NOVEMBER-DECEMBER-1959
VOLUME X
NUMBER 6

the journal of INDUSTRIAL ENGINEERING

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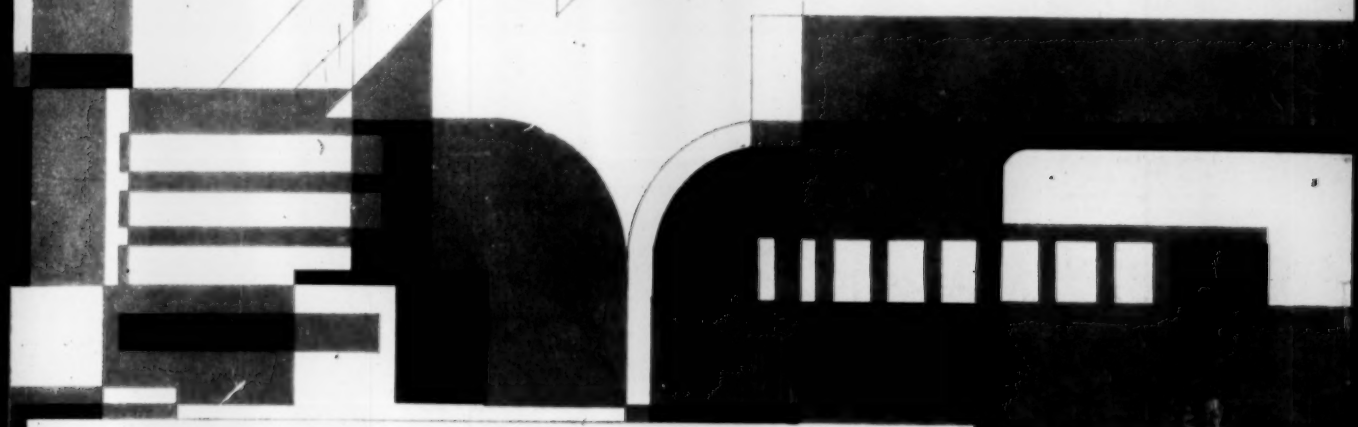

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Published Bi-monthly • AIIE Headquarters and Publication Offices, 145 North High Street, Columbus 15, Ohio • Editorial Office—A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia

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Subscription Prices: $10.00, one year; $17.00, two years.

Single Issue Price: Ninth National Conference Proceedings Issue $5.00, members; $7.00, non-members; other issues $2.50.

All Manuscripts for review should be submitted with drawings suitable for reproduction to the Editor-in-Chief, Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

Advertising Rates available from Editorial Office. Send copy and cuts to Journal of Industrial Engineering, A. French Building, 225 North Avenue, N.W., Atlanta 13, Georgia.

Membership Information available from AIIE Headquarters.

Change of Address notification should be submitted to AIIE Headquarters Office, 145 N. High Street, Columbus 15, Ohio.

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Second-class postage paid at Columbus, Ohio and at additional mailing offices.

The Scheduling of Engineering Research

by **RAYMOND VILLERS**

Consultant in Industrial Management, Rautenstrauch and Villers, and Lecturer in Industrial Engineering, Columbia University

TO KEEP pace with the complexity of modern technical developments, Engineering Research must be methodically organized. As stated by Dr. Lee L. Davenport, President of Sylvania-Corning Nuclear Corporation.

> To achieve the maximum productivity from engineering effort the time of skilled engineers must be programmed. Our nation can no longer afford the luxury of unproductive engineering effort if we are to keep pace with the technical race to which we have been challenged.

It is increasingly recognized that appropriate timing is a prerequisite to effective coordination of efforts among specialists and that the Scheduling of Engineering Research *can* and *should* be practiced.

If properly conducted, scheduling does not mean rigidity but provides the flexible framework which stimulates the freedom of thinking and the freedom of action of the individuals involved. This is why research engineers welcome scheduling after they have practiced it. At first however, it should be expected that many of them will be adverse to it.

The Industrial Engineer who has introduced production scheduling knows the problem. The switching from plant operations based upon decisions made on the spur of the moment to a system based upon the methodical evaluation of the optimum conditions of operations raises the big problem of "resistance to change." If the Industrial Engineer involved is good in human relations and therefore stimulates complete frankness, he is likely to be asked such questions as:

> "Say my friend, are you stupid? Don't you realize that it simply cannot be done here?"
>
> "Are you not aware of the fact that your scheduling system will cost us a fortune? Don't you realize that the amount of paper work involved is simply fantastic?"

Decades of experience throughout industry have answered these objections with regard to production scheduling. It is now well established that production can and should be scheduled with due regard to the selection of an appropriate system. In spite of the fundamental and obvious difference between research and production, the same concept applies to engineering research, excluding of course the "pure research" activities.

Engineering research and development does not exclude thinking, dreaming and exploring the unknown; but—and this is what separates it from pure research—it also means developing the *right product, at the right time, at the right cost*. This can best be done by scheduling which of course is no substitute for technical ability, but remarkably increases efficiency in the use of technical talents.

The purpose of this article is to describe a scheduling method which has been successful in several types of engineering research including research that requires basic advances in the state of the art. The five fundamental aspects of this method are:

1. Selecting the time unit.
2. Listing the steps of the project.
3. Providing for coordination.
4. Providing for cooperation.
5. Providing for control.

SELECTING THE TIME UNIT

Research work cannot be scheduled hour by hour or even day by day. To schedule it month by month is too vague to organize the proper coordination of efforts. Scheduling by week appears to be the realistic approach. The problem is that it is difficult to add 24 weeks to the week starting 4/18. For this reason the use of a week serial number is a real necessity. Twenty-four weeks after week 16 is week 40.

LISTING THE STEPS OF THE PROJECT

This is by far the most difficult aspect of the program. It requires technical knowledge, experience in research and also decision making ability. The following approach can be considered:

DEFINE THE PROJECT

The project may involve the development of a single item, or of a whole line of new products or the study of a new process of manufacturing. What is important is to describe clearly what it is and to assign the responsibility for scheduling it to one man, the project engineer. Whenever warranted, the project engineer may subdivide the project into several sections. In this case, he schedules the start and the completion date of each section and delegates the detailed scheduling of the sections to other engineers.

DEFINE A STEP

There is room for uncertainty and the need for a lot of thinking when it comes to categorizing certain activities

as a specific "step." A criterion is to separate the steps that can be taken by one research engineer operating on his own or supervising a small group from the steps involving another specialist or another group. Whenever warranted, it will be in order to categorize as distinct steps some activities in which one single individual is engaged, so as to provide him with the specific amount of time and the specific physical facilities he may need for each step.

LIST THE STEPS CHRONOLOGICALLY

In listing them in accordance with their expected chronological sequence, each step is assigned a serial number, using a sub-step serial number whenever more detail is required.

A special serial number system is also useful to clearly identify what can be called:

Parallel steps, which start at about the same time and will be supporting each other after they have been completed because all are needed. For instance: the environmental testing and the vibration testing of a gyroscope model.

Simultaneous steps, which are different from the parallel steps because they may exclude each other at the time they are completed. They will be taken simultaneously at increased cost for the purpose of saving time as illustrated on an exceptionally large scale by the Manhattan Project.

Alternate steps which also exclude each other, but cannot be scheduled simultaneously either for technical or for economical reasons. Alternate steps must be scheduled whenever it is reasonable to expect that various alternatives must be tried before the proper one is ultimately selected. For instance: trying at first a hydraulic control with an electrical control as the second possibility.

Many of the steps to be listed involve activities related to, but distinct from engineering research, such as:

Marketing research.
Purchasing of equipment.
Use of laboratory facilities.
Use of plant facilities for test runs.

The listing of such steps accelerates engineering research, because it avoids the distressing loss of time often due merely to lack of communication between the research engineers and the other departments.

In listing the steps there is a need for keeping the balance between too much and too little detail. It is sometimes advisable to start without going into too many detailed steps for the whole project and then, as things progress, go into more details, period by period.

STOP LISTING IF NECESSARY

One of the main objections to listing the steps is "I don't know the steps. This is an entirely new project. It has never been done before." Most of the time, this attitude is unwarranted. Sometimes however it is well founded. Whenever the research engineer is unable—and really so—to foresee the kind of approach he will follow up to the end of his project, he can split it and stop the listing of the steps at the end of the first phase, the starting point of complete uncertainty. He then schedules as step N the scheduling of the following phase, it being understood that step N should be scheduled as early as possible before the end of the first phase.

By so doing, it is possible to reconcile the need for scheduling with the fact that research, by definition, involves exploring the unknown.

ASSIGN RESPONSIBILITY FOR LISTING

The main pitfall to be avoided is to skip a step and then discover on the basis of the wisdom of hindsight rather than on the basis of foresight that the loophole is the cause of a serious delay, for instance, waiting for equipment that was ordered too late or failure to test the material early enough to know its limitations.

To avoid this pitfall, the project engineer must either have the experience required for listing all the steps of his project or split the project into the appropriate number of sections, the scheduling of which is assigned to a qualified specialist. The project engineer may or may not be a specialist in one of the main aspects of technical research. Whenever there is a need for close coordination of diversified activities, such as marketing research, cost estimates, selection of new equipment, mechanical and electronic engineering, etc., the project engineer must be well trained in all of these directions. Very often, he will be an Industrial Engineer.

PROVIDING FOR COORDINATION

After the steps have been listed in their expected chronological sequence, the project engineer visualizes *what* has to be done. He now plans *who* is going to do it and *when*.

A form such as the one shown in Figure 1 provides as many weekly columns as the project (or section) is expected to last.

The following code is suggested for posting in the appropriate column the performance of each step:

V scheduled starting week.
X scheduled completion week.

PROVIDING FOR COOPERATION

How can the need for close coordination between the specialists responsible for each step be reconciled with the need for individual freedom of thinking and action?[1] Essentially, the following four principles should be strictly adhered to:

1. The project engineer *proposes but does not impose* a schedule

[1] The answer to this fundamental question is closely related to the concept of *functional decentralization*. For a detailed study of this concept of its relationship to the organization of engineering research, see R. Villers *Dynamic Management in Industry*, Prentice-Hall (to be published in 1960); see also R. Villers "Control and Freedom in a Decentralized Company" *Harvard Business Review*, March 1954 (reproduced in the Review's *Successful Patterns for Executive Action*, 1959); and R. Villers "Concept of Flexible Integration" in *Journal of Industrial Engineering*, July 1955.

on the specialists involved. He consults with them. He coordinates the schedules accepted for each step by each specialist. He draws his own conclusions as to whether or not such acceptances make it possible to complete the project on time and within the budget. He reports to the proper level of management. He *does not have the responsibility* for being unable to meet the deadline whenever the specialists involved do not accept the assignments he proposes.

2. A schedule is not a "pledge" and cannot be expected to be met 100% of the time.
3. Whoever has accepted the schedule must notify the project engineer as soon as it appears that the schedule will not be met. He does not notify him after the due date. This is to be a rigid rule, with no exception tolerated.
4. The specialist who has accepted a schedule for a given step is listed (Column: *Responsibility*—Fig. 1) and receives his own copy of the whole schedule. This gives him a record of his future commitments and also a greater feel of responsibility. He visualizes the whole project and appreciates the extent to which his failure to perform his step on time may provoke a chain reaction that may affect the whole project. The project engineer will list his name in the same column whenever he assumes the responsibility for specific steps.

PROVIDING FOR CONTROL

Week by week, the project engineer follows up. This code is suggested:

S actual start.
O actual completion.

The project engineer is responsible for deciding whether a given delay can be remedied by a limited re-scheduling or whether it affects the whole project. In the latter case, he reports immediately to the proper level of management. Applying the previously mentioned concept of functional decentralization, the project engineer is not responsible for delays occurring because other specialists are not ready on time.

Upon completion of the project, a schedule summary report, prepared by the project engineer, will indicate:

The number of times the project had to be re-scheduled.
The reasons for delays.
The actual completion date as compared to the original schedule and the revised schedule.

Such reports will serve the purposes of:

1. Measuring the accuracy of scheduling.
2. Clarifying the responsibility of each individual.
3. Indicating what frequent causes of trouble should receive special attention.
4. Providing information for the scheduling of future projects, such as estimate of the need for scheduling more or less alternate steps in specific kinds of research.

THE CASE OF SYLCOR

At Sylcor (Sylvania-Corning Nuclear Corporation) where Engineering Research is one of the main activities of the company, the above described system of scheduling has been successfully adopted. After it had been applied for one year, a special survey was conducted which can be summarized as follows:[2]

Job No. _____ _____ Distribution Page ___ of ___ pages
Project Engineer Date Issued
Revisions

Step No.	Step Designation	Responsibility for Step	Week No.

FIG. 1. Scheduling Form

COST OF SCHEDULING

On the average, it took a project engineer about one day to schedule a 6 month project, which project involved an average total expense of about $25,000. It took about 2 hours a week, on the average, to review the schedule and, when necessary, re-schedule.

It was estimated that this amount of time, involving the project engineer and the other specialists, represented a total cost of about $1,000, i.e. 4% of the $25,000. Based upon previous experience, it was thought that even without scheduling about one half of this time would have been necessary for keeping the necessary contacts, reviewing the progress made, etc. It appears therefore that the

[2] The cooperation of Dr. John L. Zambrow, Director of Engineering and of the members of Sylcor's Engineering Unit in conducting this survey and authorizing publication of its results is gratefully acknowledged.

cost of scheduling an engineering research project can be estimated to represent an average of about 2% of the total cost of the project.

ACCURACY OF SCHEDULING

For obvious reasons, the accuracy of scheduling varies from one program to the other. It was considered however that the average results of one specific broad research program was providing a representative measurement of the actual accuracy of scheduling at Sylcor. This specific program was conducted over a one year period. It included 4 projects, which were split in a total of 40 sections. Each section was scheduled separately.

After this one year of research was completed and the technical results obtained had served their purpose, it was found that the accuracy of scheduling had been as follows:

Twenty-four sections (or 60% of the total schedules) were completed within one week of the initial schedule.

Eight sections (or 20%) were 2 to 8 weeks late because of technical problems that had not been anticipated. They were not re-scheduled because the delay did not directly affect other parts of the program.

Six sections (or 15%) were re-scheduled because of technical problems. Actual performances were in accordance with the revised schedules, which were 2 to 7 weeks beyond the original schedules.

Two sections (or 5%) had to be re-scheduled as much as 30 weeks beyond the original schedules. The delay however was due to the fact that an outside manufacturer had been late in keeping his promised delivery date for the equipment he had sold.

IMPACT OF SCHEDULING UPON TECHNICAL PERFORMANCE

It was found necessary to stimulate the creative work by making sure that the engineers involved do not work under the wrong impression that strict adherence to the schedule is their major problem. The department heads made a special effort to convince everyone involved that a schedule is nothing more than a plan of action and is therefore subject to change by re-scheduling.

On this basis, it was found at Sylcor that scheduling not only provides completion on time, not only increases the ability to forecast the duration and the cost of a research program, but also stimulates the technical aspects of engineering research. The following reasons were specifically indicated by the engineers who used the method:

1. Each project has some impact upon the other projects of the same group of engineers. With scheduling, each engineer knows precisely what those involved in other projects are doing and when. It also gives them a chance to ask other groups to explore something that would help and happens to be very close to the research they are conducting.
2. Scheduling gives the manager a good basis for planning the work of the group as a whole and thus obtain the best efficiency from the technical talents available.
3. Last but certainly not least, it was found at Sylcor that scheduling stimulates thinking because it gives a more specific and clear goal.

This article has briefly considered the mechanics of scheduling engineering research, the pitfalls to be avoided, the time and cost involved and the results that can be reasonably expected.

Obviously, the budgeting of time and money is the primary goal of scheduling. What is impressive—and stresses why the scheduling of engineering research *can* and *should* be practiced—is that actual experience shows that scheduling also stimulates technical performance. As stated by Lawrence Sama, Manager of Metallurgy Department at Sylcor:

Because you have to put it down in writing, you have to argue whether or not it should be put down. You have to think more.

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A Simplified Approach to Waiting Lines

by STUART L. KNOWLTON

Staff Industrial Engineer, Research and Development Center, Kimberly-Clark Corporation

SOME practicing Industrial Engineers and most supervisors are understandably baffled by the high-powered mathematics usually associated with the analysis and solution of queueing or waiting line problems. Aside from mathematical difficulties, the usual queueing problem also presents hurdles with respect to lengthy computation and validation of the results. In this article an alternative method for handling such cases, with a minimum of mathematics, will be presented.

For purposes of explanation, the procedure will be developed by means of a simplified maintenance example extracted from some of the studies made by our organization. It is purposely simpler than many real situations. Even though the example is less complicated than most situations likely to be encountered, the methodology is generally applicable to fairly complex queueing problems.

THE PROBLEM

Waiting lines arise when a service facility is subject to fluctuating demand which it cannot always meet. As a result, someone—or some piece of equipment—must at times wait for service. For this problem to have economic meaning, both "waiting" (or queueing) and providing service must have a cost. Of course, the classical situation is that involving a group of machines serviced by a group of mechanics—and that is the problem to be discussed.

Reduced to its essential elements, our problem is this: How many service mechanics are required for minimum cost department operation? Our approach will involve changing the question, however: If we add (or subtract) mechanics, will total costs increase or decrease?

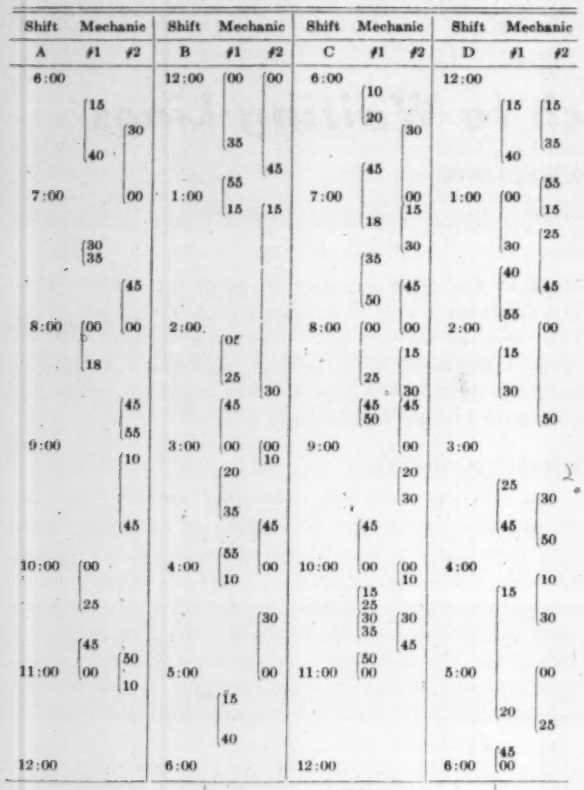
Let us assume we have 20 machines of the same type and 2 service mechanics. We wish to know the effect on costs of changing the number of mechanics.

We first need information regarding the actual service demands upon each mechanic. In most installations, service mechanics keep "call reports," which provide a chronological list of their work during a shift. Generally, such reports include the time that the man went to the job, the nature of the job, and the time he finished. In addition, most machine operators keep chronological production logs which show "down-time" and the reasons for it. For analysis, we require data, chronologically arranged, of demand upon each of the service mechanics. That information may be readily available from existing paperwork, or it may be necessary to set up a temporary system to obtain it. Our experience, so far, indicates that the data required for this type of analysis are generally already being collected as part of the normal production reporting system. We have not had to set up special recording procedures for the study.

COLLECTING DATA

The next step, of course, is to collect sufficient data for the analysis. The unit of data collection should generally be a shift, but it is wise to obtain representative days of the week and shifts of each day. These can be collected on a randomized basis or simply by picking a three or four-week period. One must guard against including periods of substantial changes in production level or in grade mix. Furthermore, the data will not be representative if technological improvements have been installed during the time covered by the data.

The service information is used to reconstruct the interaction between the machines and the two mechanics by means of a chart showing the minute-by-minute activity, chronologically arranged. Building up such a chart is an arduous task, but it is needed for both the mathematical and the present type of approach. For the mathematical methodology such information is necessary as a means of determining the shape of the service time functions, or alternatively, confirming that these distributions fit known probability curves such as Poisson, binomial, etc. For our purposes, such information, arranged in a certain manner, enables one to derive the basic data for solving the problem. This is illustrated in Figure 1, which shows each mechanic's service calls and their duration in chronological order throughout each shift. For example, the second column, headed "#1," shows that for shift A, #1 mechanic went on a call at 6:15 and finished at 6:40. Meanwhile, #2 mechanic was busy from 6:30 to 7:00. One of these tables is made up from the logs for each shift during the period under study. The peculiar arrangement is designed to permit calculations of the amount of time during each shift that: 1. no mechanic was required; 2. one mechanic was busy; 3. two mechanics were busy. This can be figured quite easily. Referring to Figure 1 at the point previously mentioned, you will note that from 6:00 to 6:15 no mechanic was busy; from 6:15 to 6:30, one mechanic was on the floor; from 6:30 to 6:40, two were occupied; and from 6:40 to 7:00, only one was required.



Summary	Shift A	Shift B	Shift C	Shift D	Total
Time No mechanic	182	100	147	120	549
Time 1 Mechanic	158	200	173	130	661
Time 2 Mechanics	20	60	40	110	230
Total	360	360	360	360	1440

FIG. 1. Mechanic's Log Sheet—Servicing 20 Machines.

The totals at the botton of the figure were obtained by summing these elapsed minutes under each category. It may be desirable to add a third column to the table in order to show mechanic requirements that could not be met by the existing two men. Our experience indicates that this is not usually necessary.

These minutes that we have summed are then converted into percentages of the total available shift minutes. Thus, we obtain what amounts to probabilities that no mechanics are busy (P_0); one mechanic is busy (P_1); etc. (P_2, P_3, . . . P_n). The sum of these probabilities should, of course, equal 1.00; similarly, sums of the minutes under each category should equal the total shift minutes available. The "P" values are then averaged for the entire period, producing Table 1. It should be noted that a third mechanic was needed occasionally in this example.

TABLE 1

2 Mechanics—20 Machines

P_0	P_1	P_2	P_{2+}
.192	.708	.075	.025

These data indicate that the average mechanic is busy about 42½% of the time

$$\left[\frac{.708 + 2(.075)}{2}\right].$$

Generally speaking, this would cause no particular alarm in such an operation.

COMPILATION OF COST DATA

The next step requires compilation of cost data. The dimension to which the economic information is related should be time, and we have found that costs based on an entire shift are a convenient measure. Another time unit can, of course, be employed if you prefer.

The costs required are of two types:

1. *Cost per service mechanic for a shift.* This figure should include not only the hourly rate but fringe benefits as well. In our example, this amounts to $2.98 an hour, or $23.84 a shift. If a shift differential exists, of course, an average rate should be used. Let's call it $24.00 a shift for each mechanic.
2. *Cost of machine down-time.* This figure can present thorny problems because several approaches are possible:

   a. Profit lost by failure to produce the product at required volume. We have not found this figure very practical in this type of problem, particularly because of joint and in-process cost analysis difficulties.

   b. Direct machine labor cost can be readily calculated. It provides a reasonably good approximation of the out-of-pocket costs. However, it does not include any cash costs which may be associated with operating the machines yet not directly attributable to any one of them.

   c. Additional out-of-pocket costs incurred by operating the department on an extended schedule. Besides direct machine labor, this figure must include other labor which is specifically required for the department's operation, such as materials handling, packers, inspection, etc. Should the department presently be operating at straight-time capacity, the costs should reflect whatever premium rates are required. In certain instances, other costs, such as power, may also be appropriate.

   We have concluded that c is the most realistic cost figure, and one that is easily understandable. It further has the virtue of accounting for output variations which result from different amounts of repair service.

In our example, this cost was figured to be $1,270.00 a shift.

From this cost information and the probabilities or usage factors previously developed, we can calculate the contribution of each mechanic—except the first. Obviously, if *no* mechanics were available, eventually all machines would be inoperative. However, we can calculate the economic contribution—in reducing waiting time—of the second mechanic, and any additional mechanics, which, if added, would reduce waiting time.

Because machines are down for repair from time to

time, we actually do not have 20 effective machines. Instead we have 20, less down-time for repair, or

$$20 - [(P_1 + P_2 + P_{3+}) + (P_2 + P_{3+}) + P_{3+}];$$
$$20 - [(.708 + .075 + .025) + (.075 + .025) + (.025)]$$
$$= 20 - 1.033 = 18.967.$$

Thus our total number of effective machines is 18.967 instead of 20. The number of effective machines is our base number, from which we calculate the contribution of a second mechanic and a possible third.

The second mechanic is required $(P_2 + P_{3+})$ of the time or $.075 + .025 = .100$. If the second mechanic were removed, the department would need to run a percent more hours:

$$\frac{.100}{18.967} = .0053 = .53\%$$

On a shift basis, we know that a second mechanic costs \$24.00; our total differential cost amounts to \$1270.00. Therefore,

$$(.0053)(\$1270) - \$24 = 6.73 - 24.00 = -\$17.27.$$

On an economic basis we cannot, therefore, justify the retention of the second mechanic. A proposal to add a third mechanic similarly would be difficult to justify:

$$\left(\frac{.025}{18.967}\right)(\$1270) - \$24 = -\$22.35.$$

To return to our first mechanic, if this type of analysis shows a negative answer, the proper course of action would be to increase the mechanic's workload by assigning more machines to him, or providing some routine, postponable jobs—such as shop work—to raise his productivity.

Applying the technique to the first mechanic:

$$\left(\frac{.708 + .075 + .025}{18.967}\right)(\$1270) - \$24 = \$29.98.$$

Obviously, this mechanic is justified. A second check reveals that one mechanic apparently is required about 81% of the time. It is doubtful that he could be expected to handle more machines, say, in another department. The assignment of additional shop work might have some merit, but it appears questionable that he would accomplish much.

We have found the preceding technique useful in situations such as described here and in handling other problems as well. It has also been applied to determine the need for standby equipment.

SUMMARY

A few general remarks about waiting lines may be helpful:

1. Experience indicates quite strongly that most real-life situations exhibit too many service facilities rather than too few. Waiting for service is not only personally annoying but appears uneconomical. This type of analysis puts the facts on the table and minimizes the importance of opinion.
2. From analyzing a variety of situations, we have concluded that service requirements and service facilities (i.e. calls for mechanics and number of mechanics) are not independent functions. In general, the greater the service facilities made available, the greater becomes the demand for them. It might be added that most mathematical models for queueing problems assume independence. This apparent dependence forced us to develop an alternative means of handling such situations, and the preceding example was the result.
3. Those familiar with Monte Carlo techniques will recognize quite readily that Table I can easily be developed by means of simulation instead of using straight historical data. Although we have not as yet tried Monte Carlo on such problems, we feel it probably has excellent potential in this area.
4. Work sampling could be used to develop the probabilities or usage factors. As yet we have not employed it for such problems, mainly because historical data has been readily available. It was easy to determine if changes in production level, grade mix, or operating methods had occurred. Such changes, of course, are somewhat difficult to predict in advance.

Experience has demonstrated that this technique represents a practical method of coping with problems of this nature. It can readily be explained to line supervision with a minimum of mathematical jargon.

FUNCTIONS AND BASES OF TIME STANDARDS

By H. O. Davidson

Revised Edition 1958

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What is An Organized Methods Improvement Program?*

by WARREN R. MELLIN

Director of Work Analysis, United Air Lines

AN ORGANIZED methods improvement program must be integrated into the total management scene and fulfill a real need if it is to be accepted, if it is to contribute, and if it is to be perpetuated. Management has many facets and performs many different operations. Some of these functions are enumerated to provide a background for developing this subject.

1. Management establishes the goals and objectives of the organization. It establishes the over-all policies and boundaries within which these objectives may be attained. It provides the means and the facilities with which operating management reaches these goals, including items such as personnel, fixed plant, tools, equipment, and supplies.
2. Management organizes the corporate structure into specific groupings of responsibilities, classifying and delegating various duties to separate departments, divisions, sections, and units. Essential to this task is the need to assure that practical responsibility for decision making should be at the lowest level in the organization where all of the facts necessary to a decision are available for evaluation and selection.
3. After having divided the organization into specific components, management's next step is to provide a means of communication so that each component does not act independently, but rather functions as a part of the whole. In this area we find a need for reports, feedback, and understanding of the total scope of the enterprise.
4. Management has the responsibility of measurement, and provides the yardsticks for measurement. There needs to be continuous appraisal of performance in relation to goals, and perpetual information as a means of improving approaches being taken to achieve objectives, or as a means of modifying goals.
5. Management develops personnel. In this responsibility, management is not only concerned with the customary improvement and upgrading, to develop and utilize the highest levels of skills, but also with developing and creating desirable employee attitudes and motivation. This function may well be the most important task of all. It involves the creation of a team concept, with men working together. It encourages understanding, a two-way flow of information and communication, and it provides a stimulus to creativity, vision, and fulfillment of human needs.

In discharging these functions, management often performs many of them simultaneously, for they are interrelated. There is a need for proper timing, and the balancing of short versus long term goals, endeavoring to achieve harmony and compatibility between them.

Basic to the performance of these operations is the fact that "managing is not just passive, adaptive behavior; it means taking action to make the desired events come to pass" (2, p. 11). In addition to the over-all goal of achieving acceptable economic performance so that the organization continues, the manager must create a productive enterprise out of human and material resources.

All of us recognize the limitations of physical resources —floor space, supplies, and equipment. A given supply of cloth will make only so many bandages of a given size. An air conditioning unit will cool only a given amount of air under given conditions. But think of the human resource. The potential of man for growth and development has an unknown upper limit. There are tremendous contributions that can be achieved through the development of human attitudes and motivation.

Thus, management has a large task—that of integrating all of the components in an enterprise. The task has been large in the past, but even today the vital transitions currently taking place make the challenge and task even greater.

There are gigantic technological advances being made in segments of American business and industry.

Satellites are circling the earth, and plans are being made to have manned space flight.

The fields of automation, electronics, and atomic energy continue to expand.

There is greater understanding and application of the social sciences in work situations.

Truly, man's breadth of knowledge is increasing and enlarging the scope of the world. Those of us in air transportation often think of the world as shrinking in size, due to the speed of jet travel. No doubt this concept is true in relation to the physical world. Even the solar system is shrinking in size when one considers travel to the moon as possible in our lifetimes.

But the world of man's knowledge is infinitely greater. Years ago a man could be qualified as a lawyer, a doctor, a poet, and philosopher. But today the field of medicine alone requires many subdivisions of knowledge, with full-time effort needed to become highly proficient in only one branch.

* Based upon a presentation to the Institute on Methods Improvement, American Hospital Association, Denver, Colorado, on December 1, 1958.

Thus, the manager today has vast responsibilities, and the dimensions of his job are growing steadily. Peter Drucker says:

> But, there will be no new men to do these staggering tasks. . . . How then can we accomplish these new tasks with the same men? There is only one answer; the tasks must be simplified. And there is only one tool for this job: to convert into system and method what has been done before by hunch or intuition, to reduce to principles and concepts what has been left to experience and rule of thumb, to substitute a logical and cohesive pattern for the chance recognition of elements. Whatever progress the human race has made, whatever ability it has gained to tackle new tasks has been achieved by making things simple through system (2, pp. 373-374).

Now the role of the organized methods improvement program becomes clearer. It has as its objective, assistance to management—Presidents, Administrators, and Governing Boards—in their task of making things "simple through system." This assistance is a vital, dynamic force, pointing toward an organized approach to problem solving, and providing a quantitative base for decision making by management. This area of Industrial Engineering shows a tremendous scope for methods improvement. But with the magnitude of the management role, and the need for methods improvement to provide assistance, there can be no boundaries to an organized methods improvement program.

NATURE OF AN ORGANIZED METHODS IMPROVEMENT PROGRAM

Against this backdrop of management, let's now turn to the nature of an organized methods improvement program.

PURPOSE

We have indicated that the purpose of an organized methods improvement program is to provide assistance to management in making things "simple through system." This is a broad spectrum approach. We might specifically add that the basic objective of methods improvement is to produce a product or service with less effort, in less time, without hurrying, with greater safety, and at lower costs. Pertinent to this concept is the idea of maximizing the resources of a company or organization to achieve the desired quality or service level at minimum costs. We need knowledge of specific tools and techniques to accomplish this mission, together with an understanding of the total process.

At the Eighth International Management Congress, Dr. Harlow S. Person said:

> Generally, throughout all areas of management, including industry, there is absence of an over-all perspective and of a comprehension of scientific management as an integrated whole. . . . The interest has been focused on mechanisms and devices . . . specialization in mechanisms and phases have become dominant (4, p. 23).

Thus, there is a caution against becoming overly technique-minded rather than problem-oriented.

With these items in mind, perhaps we should look at the definition that the American Institute of Industrial Engineers has developed for industrial engineering. This definition indicates that:

> Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

As we recognize, there are many functions within Industrial Engineering, but one of the most significant is methods improvement, so that much of this definition can apply to it. After all, the phrase systems engineering and analysis merely indicates methods improvement on a relatively large cycle or scope. In effect, at one end of the spectrum we have systems engineering with its tremendous scope. At the other end of this band, we have what many companies and individuals term work simplification, which normally refers to an extremely limited scope. Often the area of work simplification extends only to the workplace of one worker, and to the jigs, tools, or fixtures employed by him in production of a component. Somewhere between these two extremes the function of methods improvement operates, as it has been customarily construed by many individuals in the past. It is my sincere opinion that no one need be bound or even guided by this framework—rather, the role of methods improvement is just what you make it. It can be relatively stultified and limited, or it can be visionary and imaginative. We can cut our own cloth according to our concepts and our opportunities. The opportunities for methods innovations would appear to be present, for today many organizations are faced with increased demand for improved service and quality. Yet costs are rising. Productivity, in terms of work units produced per individual, is not rising as fast as employee wage rates in many cases. Indeed, there is a vital need for methods improvement.

SCOPE

In terms of scope, as you have surmised, one of my missions is to expand the concept of methods improvement. Essentially, we might visualize the subject of a methods improvement program as men at work. Our analysis must consider both the physical and non-physical elements in the work situation.

The physical elements embrace the workplace layout, tools, equipment, facilities, work flow, work procedures, materials being used, and product design. Machines must be designed with human engineering in mind, so that the physiological limitations and abilities of the human body are recognized.

The non-physical elements include the worker attitude, his needs, his perception, his motivation, and other social, psychological, or economic features. Thus a methods improvement program must consider all of these elements, stressing the need for recognition of human dignity. In many cases, it is perfectly acceptable to improve methods

within the boundaries of a given work situation. But often there are dangers to sub-optimization. Perhaps the best solution to the problem will involve extending the scope and expanding the parameters. The best solution might require tracing the complete cycle of work, backing up into other departments, or to sources of supply outside of the company, or going forward and seeing the impact of work upon succeeding work in other departments, final inspection, shipping, delivery, transportation, and use by the customer.

Looking at the human factor, the immediate work area may not be adequate. Perhaps an employee's relations with other employees, relations with supervisors, or relations with his family, his community, or his church, have a tremendous impact upon his perception, fulfillment of needs, and motivation. The concept of utilizing the resources of the whole man, and possibly job enlargement, may have a significant bearing upon the best solution or improvement to the problem.

There is often a need, also, to question assumptions or policies underlying the work situation. This is done primarily to review and to price-out alternative policies that might be considered. In all cases, the quality standards or levels of service to the public are an integral part of any work improvement study. The results of any study must consider the degree to which improvements have been made in dollar costs, service or quality levels, better or safer working conditions, and employee attitude and motivation. Thus, the initial scope of the study must be designed so that it will result in quantitative answers, insofar as possible, to basic questions.

ORGANIZATION

Another element in a methods improvement program is the manner in which the function is placed into the over-all organization. Due to the understandable and necessary variations in production and service organizations, and their diversified needs, you can appreciate that it is difficult to recommend any one organizational placement that would have comparable validity in all companies or institutions.

In terms of fundamentals, first there must be one individual who has been assigned the responsibility for coordinating a methods improvement effort. Depending upon the size of the enterprise, this responsibility could be a full-time or part-time assignment. Second, this assignment must be in the nature of a staff assignment. The individual would have authority of ideas, but not of command. Even if the person designated happens to be a supervisor or department head, when he carries out his methods responsibility with other departments, he must act in a staff capacity. He must use persuasion and encourage participation by others in order to attain optimum results.

After a centralized coordinator for methods improvement work has been designated, there are a variety of organization charts that could be drawn showing formal relationships with other functions. With an organization of modest size, this function could report to the chief administrative officer; in a large enterprise, perhaps this placement would not be completely practical. Probably many functions would like to report at the very highest level of an organization. As you recall, when quality control was recognized as a key function, this organization placement was advocated by many concerned with quality control; again, when operations research came on the horizon, the same idea was advocated. However, I would like to suggest that the fundamental organization structure is not nearly as important as the climate and atmosphere in which the function is nurtured and developed. If the climate is proper, then the departmental barriers or curtains that exist in some organizations will disappear, enabling those concerned with methods effort to do the best possible job for the organization as a whole.

There is no question that the concept of methods improvement must have support from the top echelon of management in the organization. It is only human nature for all of us to concentrate on the items that we know are emphasized by our respective supervisors and top management. If we sense that methods effort is not really backed up by top thinking, then our enthusiasm for it may be somewhat dulled and the best results will not be realized. Our initial selling must include the top level.

After a methods coordinator has been selected and placed at a level in the organization and in a climate that will permit him to function successfully, there are several approaches he can take to guide and direct the methods effort.

There might be a need for a Steering Committee, representing all departments, to guide the methods effort. An organized program can be developed so that methods analyses can be developed in each area, with a timetable indicating the over-all plan of action. This approach would highlight a formal program.

Another avenue, after orientation of all concerned on the purpose of the methods efforts, is to use a somewhat softer approach. This can be done by setting up a project in one area, and then gradually extending the effort to other areas. In each case, the methods coordinator would work with the supervisor of the area or his representative. The over-all approach, techniques and tools that can be provided by the methods coordinator can be blended with the experience and know-how of operating personnel through the formation of a team. Thus, a coordinated approach to the best possible solution can be achieved. In the event that several areas are encompassed in the scope of the study, then the team would be expanded. The expansion of the team to include others on occasion, often provides opportunities for brainstorming and the development of new approaches.

In addition to the blending of different types of experience, the team approach achieves participation—the key to acceptance of new and innovative ideas. It might be well

to caution ourselves that at the beginning of a methods program, or the beginning of a project, it is desirable to undersell, rather than oversell, the estimated results or benefits from a change.

ALLOCATION OF EFFORT

Related to the need for directing a methods effort, we might ask ourselves how effort should be expended with reference to methods improvement. There are three specific and discreet levels of effort allocation.

Let's elaborate briefly on each of these levels:

1. Effort directed to getting the most out of the present system . . .
2. Effort directed towards improving the present system . . .
3. Analyses and development of entirely new systems (1).

First—getting the most out of the present system. For various reasons, on a short range, immediate result approach, we may want to measure all of the components in a given situation and determine if, based on present methods, the organization is getting maximum return for the dollars expended. This may involve an analysis of manpower effort, materials, equipment, and inventories, and it results in measurements of the present system. A situation like this could occur where you improved the system a few months ago, but for some reason it does not appear to be working properly today. The problem is really to assure that one is achieving best possible results with this system. Results through this level of effort are often modest, and they can be apparent in days or weeks.

Second—improving the present system. This concept accepts certain restrictions in the way of management philosophy, policies, and there also might be certain restrictions in the way of facilities or equipment that might have a bearing on the system; but, in any event, it would be directed toward improvement of the system. This level of effort would make improvements in work place, layout, possibly work flow, details of the operations to be performed, better balancing and scheduling, and other related activities. The effort would take somewhat more time, perhaps, consuming from a few weeks to a few months, depending on the complexity of the operation and the potential for improvement. It would require relatively skilled analytical effort.

Third—developing an entirely new system. This concept has few limitations. It might require several years of time and would require highly skilled effort. The greatest payoff, in increased productivity and dollar return, is in this area.

We should ask ourselves, then, whether we are spending too much time in merely maximizing the present system by assuring compliance with procedures, for example, and not in improving it. And the second question is whether we might be spending too much time in improving the system without any consideration of the third category—developing a totally new concept—which has the greatest return in tangible terms as well as human satisfaction.

APPROACH

In developing an approach to a methods improvement project, it would appear desirable at the outset to have a clear idea of the project purpose and procedure. Satisfactory communication can be achieved best through the development of a written document which, in brief form, outlines the elements necessary in a study. The headings include purpose, problem, scope, approach, and timetable.

First, among the items to be clarified, is the basic purpose of the study; this paragraph should state the purpose in terms of fundamental objectives that do not limit the choice of solutions. For example, a purpose would be stated "to develop a better way of handling data" rather than "to make a computer feasibility study."

A *second* paragraph should outline the problem leading to the study, or provide background material which orients those concerned and brings them up to date so that the status of the over-all situation is understood.

Third, the scope should provide a fence surrounding the study, so that the functions to be studied are clear, and so that the physical area is spelled out. The operation cycle should be defined, so that we know where the study begins and where it ends.

Fourth, the approach should define those individuals having basic responsibility for the study, specifically stating who is the project leader; determining whether a team approach should be used, and who else will participate in the project, perhaps at various stages. This paragraph should contain the detailed steps to be taken that will portray and measure the present condition, the types of analysis that will be made, the means of developing new approaches to the situation, the analytical devices that will assist evaluation and selection, the means of testing or measuring the proposed solution, and means of follow through. Here we might comment on the desirability of using a pilot installation where feasible, prior to extending the new method to many different areas at once. This step often provides increased knowledge of the new method in actual operation, and provides opportunity for further refinement prior to wholesale installation. The questioning attitude is paramount in understanding the nature of the current operation as well as developing ideas for improvement. You are familiar with specific approaches to assist in analysis and development of new ideas. Some are five step approaches, others are seven step approaches. Also, there are numerous check lists of questions and principles of motion economy to assist in analysis and idea development. All of these aids are most helpful in the improved solution to a specific problem. You may have read one of the monthly mottoes selected by the Better Mottoes Association of Los Angeles, which said: "Are you working on the solution—or are you part of the problem?" I think all of us are aware of situations where this question has particular significance.

Fifth, there should be a timetable for each of the steps necessary, so that an estimate of the time necessary, and manpower to be expended can be obtained in advance. Often this step can raise questions as to the estimated manpower in relation to the estimated benefits to be obtained. This question may then change the scope of the project. A key item in the timetable is to allow time for the installation of the new method and follow up to assure that it is working as well as anticipated, and to see whether any further improvements can be made.

It is hard to overemphasize the value of "before and after" pictures. Often those of us in organizations are so enthusiastic about going ahead and achieving improvement that we don't take the extra time at the outset to provide, figuratively, a photograph of the current operation in terms of service or quality, manpower, costs, and

time lag. Only in this way do we have an accurate record or a base against which to provide quantitative measurements of progress. Those of you who have dealt with outside consulting firms know that customarily this is a requirement of theirs, so that they have a firm base for the evaluation of their efforts.

In any event, the development of a written, organized approach to methods improvement provides a medium for effective communication, and the obtaining of necessary management approvals prior to the start of a study. It also provides check points at various intervals to assure that the project is on course, and is a device for control and direction of over-all effort.

TOOLS AND TECHNIQUES

After the over-all objectives for a methods project have been clarified, and a step-by-step approach developed, there is a need for determining the tools or techniques that might provide a means of analysis or solution. Again, I might comment that at no time should we become technique-oriented—we must continue to be problem-minded. Nothing is more useless than the right answer to the wrong problem. If we are technique minded, we may be running around with an answer, looking for the problem it fits. Now with this word of caution added, we might list some of the specific techniques that can be helpful in problem solving. Many of them—perhaps most of them—are well known to you. Yet sometimes we don't realize how many different tools we have at our disposal. Almost every one of them could have application at certain times in methods improvement studies.

Some of the old stand-bys in methods analysis include flow diagrams, flow process charts, operation process charts, simo-charts, man and machine charts, Gantt charts, motion pictures, memo-motion, and micro-motion. In those cases where times values are a necessary adjunct to methods analysis, there is time study, standard data, and pre-determined times. Many studies will have valid applications for the tools of personnel analysis and principles of motivation, perception, and creativeness.

Other analytical tools include quality analysis, engineering economics, marginal analysis, investment analysis, cost analysis, value analysis, organization analysis, job analysis and evaluation, wage payment, work sampling, data collection, computers, mathematical programming, probability theory, simple and multiple correlation, analysis of variance, tests of significance, sampling, queueing or waiting line theory, Monte Carlo, model building, simulation, mathematical model, scale model, human engineering, communications theory, analytical graphics, control charts, nomographs, forms analysis, reports analysis, report writing, and graphical chart presentation. In this list you will recognize certain techniques commonly associated with operations research. But they are equally available and useful to the man concentrating on methods improvement.

But our list is not entirely complete, for the very approaches that you use to define a problem are techniques in themselves. Here we might list the scientific approach, the questioning attitude, the problem approach outline, and the team approach. Each has a definite value and has certain characteristics that make it a distinctly different tool.

In the use of some of the tools thought of as being somewhat more sophisticated, and requiring deep knowledge of mathematics and statistics, you will recognize that one needs intimate acquaintanceship for proper use and application.

In the event that a logical area for application occurs and detailed knowledge of waiting line theory is not readily available, one should go to another source—another organization, an outside firm, university, or a consulting firm—for assistance. Perhaps in a methods study of four weeks, the use of specialized assistance for a day or two may well unlock the answer. In the event that a consultant is retained, it is desirable to have one or two individuals assigned to work with him so that at the conclusion of his effort there has been a transfer of knowledge from the consultant to men within the organization.

As all of us can appreciate, we should use whatever technique that can be used in a successful solution at the lowest expenditure of time and money to achieve our goal. As mentioned, we should not be overly enamored of some of the so-called "newer" techniques unless they are well adapted to particular situations. At the same time, knowledge and use of probability theory will insure, for example, that we do not design a work situation necessary to handle 100% of all occurrences. There often is an economic balance in a work situation so that with a considerable savings in outlay for equipment or floor space, an installation is made with the knowledge that during one or two days a year there will be an overload. In applications of waiting line theory, there is a need to price-out alternate levels of service, with a dollar tag affixed to each one, as a basis for policy determination. For example, many doctors today will deliberately create a waiting line of customers in their reception rooms in order that they may make maximum use of their time in several different examination rooms. In a service organization there needs to be a delicate balance between an economic concept on the one hand and a service concept on the other. With the economic concept a situation with a long waiting line would be desirable if the customers or patients waited. If a pure service concept prevailed, the customers or patients would be delighted with the service, but costs would skyrocket—and the clients might not favor the increased costs.

In all cases, we need to continue to broaden our horizons to know when to use which tool. We must remember to use a yardstick on occasion rather than a micrometer. In short, those concentrating on methods improvement must think of themselves as general practitioners rather than specialists.

TRAINING

As a means of increasing participation of others, achieving their acceptance, and making their contribution of time and effort more meaningful, each of you recognizes the role of training. As Oliver Wendell Holmes once said: "Man's mind, stretched to a new idea, never goes back to its original dimensions."

This is a major function of the methods coordinator—to train others in methods and techniques of approaching and solving methods problems. I will not deal with detailed training techniques, for I am sure that each of you is conversant with them. There is, however, one thought I would like to express, along the line of training.

Many organizations are continuing to train all supervisors from many different departments in the principles of work simplification, as they are commonly known. This approach may be the only one that could be used in an organization of modest size, but as a company becomes somewhat larger, this concept has limited application. For example, it has been our company's experience that if one can possibly gather together the individuals concerned with the same function in an organization, one can create more training in depth and much broader results. Also, this approach means that one does not restrict training to work simplification techniques, as such, but expands the horizons to embrace a larger scope.

For example, quite some years ago, staff specialists and first line supervisors from many departments of United Air Lines were trained in a work simplification course that lasted eight hours or so. Although there was interest and it was a good course, the results were only average over a period of time. In looking back, perhaps the real contribution of this course was to assist in creating a favorable climate, and improving the attitudes of all concerned towards methods improvement. Possibly this approach paved the way for the present concept which was illustrated a few months ago when staff methods specialists from each of the Reservations offices on United's system were brought together for an intensive methods workshop. One hundred percent of all of the examples were in the area of Reservations. As you probably can appreciate, there are several different areas within the office that are quite individual and specific. For each subject discussed, there was a 15-minute narrative by way of concept and background on the part of the trained instructor. Then there was another one-half or three-quarters of an hour where the instructor, using a given technique, would actually solve a particular problem. Immediately following, there was another three-quarters of an hour devoted to a similar problem to be solved by the group. Following this session, there was a joint discussion of solutions to the problem.

This workshop was "hard-hitting," and the subjects covered included flow diagramming, time study, flow process charting, man and machine charting, frequency distribution, probability, work distribution, manpower scheduling, work sampling, and waiting line applications. A detailed questionnaire was given to all of the participants at the conclusion of this two-day session, and the reception of this course was the best achieved to date for methods improvement within United Air Lines. There was also a strong desire for a one-day follow-up session, which will be afforded in the near future. I mention this illustration because it is a significant departure from the concept of trying to train individuals from various departments at the same time.

SELLING RESULTS

In the final analysis, the value of the hard work that has gone into a methods improvement study will be dependent to some degree on ability to sell the results. The problem will be minimized, of course, if there has been a team effort and there has been agreement on the part of all concerned. If there has not been a team effort, the problem will be minimized if the coordinator responsible for the project has received good cooperation from the using department and if he has communicated with them continuously so that they have been aware of the status of the study as it progressed. In all cases, the using department should have reviewed a draft of the final report prior to official typing or submission. The final report, as such, is only a necessary documentation for final reference. Nothing in it should come as a surprise to anyone. There must be effective communication before the report is written.

The report itself should set forth clearly and definitely the basic conclusions of the study, and specific recommendations, backed up by quantitative exhibits as necessary. Results of the study should be portrayed in terms of quality or service features, manpower savings, floor space, equipment, amortization, and costs. In some cases, alternatives should be prepared, especially where there are areas requiring management policy decisions. It is often desirable to have the installation plan call for several phases, so that a gradual transition may be evolved—in other words, evolution not revolution. As a means of simplifying a discussion of the findings, it is often desirable to prepare brief graphic charts as an aid for communication. With this preparation for presentation, the probabilities of achieving agreement should be enhanced.

SUMMARY

In summary, we might enumerate the characteristics or elements in an organized methods improvement program that should be highlighted in establishing and conducting the program for successful results. These are the elements that will enable us to change from the present day concepts to newer concepts of greater service or greater dollar savings to an organization.

1. *Human element.* Any methods improvement program must recognize the attitudes and motivation of the individuals and their role and potential contribution in the work situation. Job enlargement and recognition of effort are vital.

2. *Objectivity.* Objectivity must be maintained if a methods improvement effort is to optimize the situation, recognize interrelationships of various departments, and serve the needs of the total enterprise.
3. *Staff.* Methods improvement is a staff function, with the authority of ideas, not of command. Its techniques are those of persuasion, guidance, direction, and training, with a keen sense of timing added.
4. *Participation.* Only through participation of those in the using departments can complete acceptance of new ideas, and development of additional innovative concepts be achieved. Continuous and effective communication is a necessity.
5. *Interest.* The interest and support of top management for any methods improvement effort must be enlisted. After initial support, there must be continuous feedback on the status and contribution of methods projects to retain this support.
6. *Trained approach.* The coordinator must display a trained and organized approach to problem solving. There must be some mental discipline evidenced if a scientific approach is to be taken. A written outline for any significant methods study would appear essential.
7. *Atmosphere.* There must be an attitude or climate that is favorable toward new ideas if methods effort is to grow and develop.
8. *Latitude.* The latitude or scope of an organized methods improvement program must be broad, when necessary, in order to achieve best results. Included here is the responsibility to price out alternate courses of action, with a quality and service level and price tag affixed to each, as a basis for management decision making and policy formation.

If these elements are present, a methods improvement effort will make significant contributions and will achieve continuity. The potential is tremendous, for really, the field of methods improvement and scientific management has only begun. By way of illustration, I would like to paraphrase an item from *Advanced Management.*

The author quotes Jean Predseil, who stated that the Industrial Revolution has occurred very recently in the history of man. Thus, "we are dealing with a movement which is in the vigor of its youth and not in its decline" (3).

The author points out that in order to understand the progress of man in relationship to antiquity, one needs a new mental image. The known period of man's history is 30,000 years. To aid us in understanding the meaning of this measurement, the author compresses the 30,000 year history into 12 months, as follows:

January	1....	(Beginning of Man) The Age of Stone . . .
October	18....	Iron Age starts, . . .
December	8....	Christian Era begins . . .
December	29....	Louis XVI ascends the throne of France . . .
December	30....	In the first 18 minutes of the morning, Watt invents the steam engine . . .
		And thus we reach the last day of the year.
December	31....	5:31 A.M. Edison invents the first incandescent lamp . . .
		4:14 P.M. World War I begins . . .
		Midnight Atomic Bomb explodes upon Hiroshima. The Atomic Era begins (3).

Think of the achievements in scientific management in only a few "days" of our history, and of the tremendous horizons stretching before us. This is our challenge!

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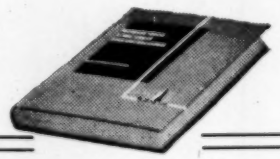

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Solving Linear Programming Problems with Variable Parameters

by C. M. SHETTY[1]

Department of Industrial Engineering, The Technological Institute, Northwestern University

THE simplex method of solving linear programming problems forms a convenient method of studying systems which can be represented by a *linear programming model* where the criterion function and the restrictions are a linear combination of the variables (2), (3). In the formulation of a linear programming model it is presumed that the explicit data (parameters) of the problem are fixed. However, in many cases, these values are subject to change. In some situations, the values may change with time. For example, in a production and marketing context, the maximum demand for a product is subject to seasonal fluctuations. In this case, if the demand for various products at certain critical time-points are considered, the corresponding optimal number of each of the items to be produced is of interest. In situations where management contemplates action to change the values of the constants, information on the effect of this action on the optimal values of the variables can be of importance. For instance, such a situation arises when an expenditure to increase the rate of production is being considered. Further, in some other situations, the values of the parameters may not be known precisely. When only estimates of the values are available, the study presented in this paper may be helpful in evaluating the current operation of the system, as it provides a method of obtaining the solution for various combinations of the values of the parameters. The purpose of this article is to provide a methodology for the study of such a system when the parameters are either subject to change or not deterministic.

A linear programming model where the parameters can be cast in parametric form has been considered by Saaty (3), (4). Such a case arises, for example, when the constants of the problem can be expressed as functions of time, and the method presented by him then yields a correspondence between optimal solutions and ranges of time-values of the constants. When only one of the constants of the problem is changed without necessitating a change of *basis* in the final simplex tableau, the method of obtaining the optimal values of the variables is given in (5). In this paper we will deal with the following question: "When a set of constants of the problem are changed (with or without necessitating a change of basis) what is the optimal solution?"

[1] The author is indebted to Dr. Loring G. Mitten of Northwestern University for constructive criticism during the course of the study and for valuable suggestions in the presentation of the article. Appreciation is also due to the referee for critical comments.

NOTATION

It may be recalled that in the simplex method the *initial* tableau is formed by first expressing the restrictions in the form:

$$\sum_{j \notin B} a_{ij}x_j + x_i = b_i, \qquad i \in B, \qquad \text{Eq. 1.}$$

where $i \in B$ means x_i is a basis variable in the initial tableau. By iteration, one can then arrive at the *final* solution tableau which maximizes:

$$C(\mathbf{x}) = \sum_{j} c_j x_j \qquad \text{Eq. 2.}$$

In the study it will be necessary to relate the elements of the initial tableau with the elements of the final tableau. Consider the initial tableau. Corresponding to this tableau we have already defined a set $B = \{j \mid x_j \in \text{basis in the initial tableau}\}$. The element at the intersection of the row corresponding to a variable $x_P (P \in B)$ and the column corresponding to a variable x_Q will be denoted by a_{PQ}. Likewise, the element b_P will be in x_P's row. Further, we will denote the elements of the last two rows by

$$z_j = \sum_{i \in B} c_i a_{ij} \quad \text{and} \quad w_j = (c_j - z_j).$$

To illustrate the notation, in Table 2 corresponding to the numerical example given later, we have $B = \{4, 5, 6\}$, $a_{32} = 2$, $b_4 = 480$, $z_4 = 0$ and $w_3 = 10$.

Now consider the final tableau, the elements of which will be denoted with a prime. The basis variables in this tableau can be identified by defining a set $B' = \{j \mid x_j \in \text{basis in the final tableau}\}$. The element at the intersection of x_R's row ($R \in B'$) and x_T's column will be denoted by a_{RT}'. Similarly, the element b_R' will be in x_R's row. In the last two rows we have the elements

$$z_j' = \sum_{i \in B'} c_i a_{ij}' \quad \text{and} \quad w_j' = (c_j - z_j').$$

For example, in Table 3 given later, we have $B' = \{3, 2, 6\}$, $a_{31}' = 0.4$, $b_3' = 112$, $z_1' = 22$ and $w_1' = -2$.

We now consider the constants which are to be changed. These constants can be divided into the following mutually exclusive and collectively exhaustive sets:

a. Set $S_a = \{a_{ij} | \Delta a_{ij} \neq 0, j \in B'\}$,

i.e., changes in the coefficients (in the restricting equations) of the variables which are in the final basis.

b. Set $S_{a'} = \{a_{ij} | \Delta a_{ij} \neq 0, j \notin B'\}$,

i.e., changes in the coefficients (in the restricting equations) of the variables which are not in the final basis.

c. Set $S_b = \{b_i | \Delta b_i \neq 0\}$,

i.e., changes in a subset of the restraining constants.

d. Set $S_c = \{c_j | \Delta c_j \neq 0\}$,

i.e., changes in the coefficients (in the criterion function) of a subset of the variables.

When the elements $a_{ij} \in S_a$, $S_{a'}$, $b_i \in S_b$, and $c_j \in S_c$ are changed in the initial tableau, we will denote the new elements by a star. We then have:

$$\begin{aligned} c_j^* &= c_j + \Delta c_j, \\ b_i^* &= b_i + \Delta b_i, \text{ and} \\ a_{ij}^* &= a_{ij} + \Delta a_{ij}. \end{aligned}$$

Further, we will denote the column with elements b_i^* by b^* and the columns with elements a_{ij}^* by a_j^*, $j = 1, \cdots, m+n$.

CHANGE IN CONSTANTS OF THE PROBLEM

The problem can now be restated as follows: Given the final simplex tableau (solution tableau) which gives the non-negative values of the variables, x_j, satisfying Eq. 1. and maximizing Eq. 2. , we are required to find the solution to the changed problem where the restrictions are given by:

$$\sum_j a_{ij}^* x_j = b_i^*, \qquad i \in B, \qquad \text{Eq. 3.}$$

and the criterion function to be maximized is given by:

$$C(\mathbf{x}) = \sum_j c_j^* x_j. \qquad \text{Eq. 4.}$$

We now proceed to discuss the method of solution. In Algorithm 1a that follows we will first consider the effect of changes in $a_{ij} \in S_a$ (taking one element at a time) on the elements of the matrix A^{-1} defined at Step 1 of the algorithm. Using the matrix thus obtained we will next form a tableau taking into account the change in all the constants. (When a_{ij}, $j \in B'$, is not changed this tableau can be obtained by Algorithm 1b which does not involve matrix multiplication.) We will then test the tableau for optimality and, if necessary, proceed further by the simplex method to obtain an optimal tableau.

Algorithm 1a

Step 1. Consider the initial tableau. Let the *ordered* arrangement of the basis variables (reading vertically down in the column titled "basis") be $x_p, x_q, \cdots$. Now consider the columns $j \in B$ in the final tableau. Form an $m \times m$ matrix by rearranging these columns in the order $x_p, x_q, \cdots$, reading from left to right. Denote this matrix by A^{-1}. Proceed to Step 2 with A^{-1} as the current inverse matrix.

Step 2. Consider a previously unselected element of the set S_a. (For the first iteration it may be any $a_{ij} \in S_a$.) Denote the elements of the *current inverse matrix* by $\hat{a}_{ij}$. Change its elements by:

$$\Delta \hat{a}_{ij} = \begin{cases} 0, & j \in B' \\ \hat{a}_{iI} \sigma_{IJ} \hat{a}_{Jj}, & j \notin B', \end{cases}$$

where

$$\sigma_{IJ} = -\frac{\Delta a_{IJ}}{1 + \Delta a_{IJ} \hat{a}_{JI}}.$$

Proceed to Step 3.

Step 3. The matrix thus obtained will now be the current inverse matrix. Repeat Step 2 for each element of the set S_a. Denote the inverse matrix obtained when all the elements of S_a are considered by A^{*-1}. When this matrix is obtained, proceed to Step 4.

Step 4. Form a tableau with elements a_{ij}'' and b_i'' ($i \in B'$, $j = 1, \cdots, m+n$) as follows:

a. $$a_{ij}'' = a_{ij}', \qquad i, j \in B',$$

i.e., recopy the elements (in the final tableau) in the columns corresponding to the basis variables.

b. $$b'' = A^{*-1} b^*, \text{ and}$$
$$a_j'' = A^{*-1} a_j^*, \qquad j \notin B',$$

i.e., for the remaining columns premultiply the corresponding column in the new initial tableau (with elements b_i^* and a_{ij}^*) by A^{*-1}. If $b_i'' \geqq 0$, $i \in B'$, proceed to Step 5. Otherwise proceed to Algorithm 2 to obtain the solution tableau (with a different basis).

Step 5. Enter the values of c_j^* (the changed values of c_j) in the appropriate columns and rows. Compute

$$z_j'' = \sum_{i \in B} c_i^* a_{ij}'' \text{ and } w_j'' = (c_j^* - z_j''), \qquad j = 1, \cdots, m+n.$$

Enter them in the respective rows to complete the tableau. If we have $w_j'' \leqq 0$, $j \notin B'$, the tableau is the solution tableau, and the optimum values of the variables are given by:

$$x_i = \begin{cases} 0 & i \notin B' \\ b_i'' & i \in B'. \end{cases}$$

Otherwise, apply the simplex method to get the solution tableau (with a different basis).

Algorithm 1b

When set S_a is a null set (i.e., when no elements a_{ij},

$j \in B'$, are changed), the following steps give an alternative method of solution.

Step 1. From the final tableau obtain a tableau with elements b_i'' and $a_{ij}''(i \in B', j=1, \cdots, m+n)$ using the following rules:

a. The elements corresponding to the column b' are given by:

$$b_k'' = b_k' + \sum_{b_i \in Sb} \Delta b_i a_{ki}', \qquad k \in B'.$$

b. Recopy the columns in which no element a_{ij} has been changed, i.e.,

$$a_{iJ}'' = a_{iJ}' \text{ when } a_{iJ} \notin S_{a'} \text{ for } every\ i \in B.$$

c. In each of the remaining columns (e.g. $j=J$), the elements in the tableau in column J are given by:

$$a_{kJ}'' = a_{kJ}' + \sum_{a_{iJ} \in S_{a'}} \Delta a_{iJ} a_{ki}', \qquad k \in B'.$$

Proceed to step 2.

Step 2. We now have all the elements in the body of the tableau. Proceed to Step 5 of Algorithm 1a if $b_k'' \geqq 0$, $k \in B'$. Otherwise proceed to Algorithm 2.

PROCEDURE FOR HANDLING NEGATIVE b_i'' IN A SIMPLEX TABLEAU[2]

Application of Step 4 of Algorithm 1a or Step 1 of Algorithm 1b may lead to a tableau with one or more $b_i'' < 0$, which means that a change of basis is necessary. In such a case, further steps given in Algorithm 2 that follows are necessary to obtain a solution tableau. The first step in Algorithm 2 is to make the value of each of the variables non-negative. This is done by multiplying the equations corresponding to the rows with $b_i'' < 0$ by -1. A dummy variable is then introduced into each of these equations to give a new basis variable in the respective row. The simplex method can then be applied to obtain a solution tableau.

Algorithm 2

Consider the tableau in which one or more b_i'', $i \in B'$, are negative. Let a set N define the rows corresponding to these elements, i.e., $N = \{i \mid b_i'' < 0,\ i \in B'\}$. Let there be h elements in this set. We will have to introduce h new dummy variables into the tableau. We will denote these by $x_{m+n+1}, \cdots, x_{m+n+h}$. Let their coefficients in the criterion function be $-M$ (i.e., $c_{m+n+1}^* = \cdots = c_{m+n+h}^* = -M$), where M is a large positive number.

Step 1. Form an *augmented* tableau as follows:

a. Replace each x_i, $i \in N$ (in the column titled "basis"), by a dummy variable $x_{m+n+1}, \cdots, x_{m+n+h}$. Change the sign of each of the elements in row $i \in N$ in the body of the tableau.

b. Add h new columns to the tableau corresponding to the h dummy variables added. For the elements in the body of the tableau in these added columns, enter zero in all rows except in the row in which it is the basis variable. In the latter, the coefficient is 1.

c. Enter the coefficients c_j^*, $j=1, \cdots, m+n+h$, in the appropriate columns and rows to complete the simplex tableau.

Proceed to Step 2.

Step 2. Proceed by the simplex method until the solution tableau is obtained.

AN EXAMPLE

The steps in the algorithm given above will now be illustrated using the following problem, which was presented in an earlier issue of this JOURNAL (5):

TABLE 1

Product	1	2	3
Production rate (pcs. per hour)	20	60	15
Storage space (sq. ft. per pc.)	4	2	3
Profit ($ per pc.)	20	10	20

A manufacturing concern deals in three products, 1 through 3. The production rates, space requirements for storage, and profits are as given in Table 1. The maximum time available for production may be assumed to be 8 hours per day, and the maximum amount of storage space available as 400 square feet. Further, suppose that the maximum demand for product 2 is expected to be 70 pieces per day. The problem is then to find the number of pieces of each product to be produced per day to maximize profit.

Denoting the number of pieces of each product produced per day by x_1, x_2, and x_3 respectively, the problem can be expressed as:

Maximize:

$$C(\mathbf{x}) = 20x_1 + 10x_2 + 20x_3,$$

subject to the restrictions:

$$\begin{aligned} 3x_1 + x_2 + 4x_3 + x_4 &= 480, \\ 4x_1 + 2x_2 + 3x_3 + x_5 &= 400, \\ x_2 + x_6 &= 70, \end{aligned}$$

where the time-restriction is expressed in minutes, and x_4 through x_6 are the slack variables.

From the above set of equations, the initial tableau (Table 2) can be formed. Proceeding by the simplex method, we have the final tableau given as Table 3.

In the foregoing problem, suppose we wish to examine the effect of the following changes:

a. Increase in production rate of products 1 and 3 to 30 and 20 pieces per hour respectively, i.e., we now have $a_{11}^* = 2$ and $a_{13}^* = 3$.

b. Decrease in storage space for product 3 to two square feet per piece, i.e., $a_{23}^* = 2$.

[2] This can be handled either by the simplex method or by the dual method (1). In this article the former method is given.

TABLE 2

		c_j	20	10	20	0	0	0
c_i	Basis	b	x_1	x_2	x_3	x_4	x_5	x_6
0	x_4	480	3	1	4	1	0	0
0	x_5	400	4	2	3	0	1	0
0	x_6	70	0	1	0	0	0	1
	z_j	0	0	0	0	0	0	0
$w_j = (c_j - z_j)$			20	10	20	0	0	0

c. Decrease in estimated maximum sales of product 2 to 50 pieces per day, i.e., $b_6^* = 50$.

d. Change in profit to \$25, 20 and 15 for products 1, 2, and 3, respectively, i.e., $c_1^* = 25$, $c_2^* = 20$ and $c_3^* = 15$.

From the above we have $S_a = \{a_{43}, a_{53}\}$, $S_{a'} = \{a_{41}\}$, $S_b = \{b_6\}$ and $S_c = \{c_1, c_2, c_3\}$. Table 4 gives the body of the new initial tableau with elements $b_i \in S_b$ and $a_{ij} \in S_a$, $S_{a'}$ changed to the new values.

TABLE 3

		c_j	20	10	20	0	0	0
c_i	Basis	b'	x_1	x_2	x_3	x_4	x_5	x_6
20	x_3	112	.4	0	1	.4	−.2	0
10	x_2	32	1.4	1	0	−.6	.8	0
0	x_6	38	−1.4	0	0	.6	−.8	1
	z_j'	2560	22	10	20	.2	4	0
$w_j' = (c_j - z_j')$			−2	0	0	−2	−4	0

From Table 3 the inverse matrix, A^{-1}, is as shown below. The variables corresponding to the columns and rows of this matrix are indicated at the top and to the right of the respective columns and rows. This will facilitate relating the elements of the matrix with the equations given in Algorithm 1a. It may be noted that this relation holds for all matrices derived from it in subsequent operations.

$$A^{-1} = \begin{array}{c} \begin{matrix} x_4 & x_5 & x_6 \end{matrix} \\ \begin{bmatrix} .4 & -.2 & 0 \\ -.6 & .8 & 0 \\ .6 & -.8 & 1 \end{bmatrix} \end{array} \begin{matrix} x_3 \\ x_2 \\ x_6. \end{matrix}$$

For a change in a_{43}, using Step 2 of the algorithm, we have

$$\sigma_{43} = -\frac{-1}{1-.4} = \frac{1}{.6}, \text{ as } \Delta a_{43} = -1 \text{ and } \hat{a}_{34} = .4.$$

Hence, the new inverse matrix is given by:

$$\begin{bmatrix} .4 + \dfrac{(.4)(.4)}{.6} & -.2 + \dfrac{(.4)(-.2)}{.6} & 0 \\ -.6 + \dfrac{(-.6)(.4)}{.6} & .8 + \dfrac{(-.6)(-.2)}{.6} & 0 \\ .6 + \dfrac{(.6)(.4)}{.6} & -.8 + \dfrac{(.6)(-.2)}{.6} & 1 \end{bmatrix}$$

$$= \begin{array}{c} \begin{matrix} x_4 & x_5 & x_6 \end{matrix} \\ \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & 0 \\ -1 & 1 & 0 \\ 1 & -1 & 1 \end{bmatrix} \end{array} \begin{matrix} x_3 \\ x_2 \\ x_6. \end{matrix}$$

We now repeat Step 2 for the change in a_{53} (the other element in S_a). We have

$$\sigma_{53} = -\frac{-1}{1+1/3} = \frac{3}{4}, \text{ as } \Delta a_{53} = -1 \text{ and } \hat{a}_{35} = -\frac{1}{3}.$$

As this is the final element of S_a to be considered, we have:

$$A^{*-1} = \begin{bmatrix} \frac{2}{3} + (-\frac{1}{3})(\frac{3}{4})(\frac{2}{3}) & -\frac{1}{3} + (-\frac{1}{3})(\frac{3}{4})(-\frac{1}{3}) & 0 \\ -1 + (1)(\frac{3}{4})(\frac{2}{3}) & 1 + (1)(\frac{3}{4})(-\frac{1}{3}) & 0 \\ 1 + (-1)(\frac{3}{4})(\frac{2}{3}) & -1 + (-1)(\frac{3}{4})(-\frac{1}{3}) & 1 \end{bmatrix}$$

$$= \begin{array}{c} \begin{matrix} x_4 & x_5 & x_6 \end{matrix} \\ \begin{bmatrix} \frac{1}{2} & -\frac{1}{4} & 0 \\ -\frac{1}{2} & \frac{3}{4} & 0 \\ \frac{1}{2} & -\frac{3}{4} & 1 \end{bmatrix} \end{array} \begin{matrix} x_3 \\ x_2 \\ x_6. \end{matrix}$$

Applying Step 4 of the algorithm we get Table 5. We find that b_6'' is negative. Hence, we proceed to Algorithm 2, and replace x_6 by a dummy variable x_7 as shown in Table 6. Application of the simplex method will then give the solution tableau given at Table 7. The value of the criterion function is now \$3,225.00.

CONCLUSIONS

It may be noted that when the solution tableau is obtained by the application of the algorithms presented in this paper, the effect of further changes in the constants can be studied using this tableau, *except when some* a_{ij}, $j \in B$, *has been changed.* However, the necessity to change any a_{ij}, $j \in B$, does not arise if the basis in the initial tableau consists of only slack and/or dummy variables.

When the constants of the problem are changed, the method presented in this paper will result in considerable saving in time and effort in obtaining the solution, compared with the alternative method of applying the simplex method directly to the changed problem. This is so, particularly in the case of problems involving a large number of variables. If necessary, the steps given in the algorithm can be programmed on a computer to facilitate computation.

The study of the effect of changing the constants can result in a better understanding of the problem by providing a keener insight into the limitations involved. It can help in planning to meet changing conditions, and hence result in a more profitable operation. The algorithms given in the paper form a convenient method for obtaining the solution for alternative conditions. It can, therefore, provide a basis for a more logical decision when alternative proposals are under consideration. Further, when the values of the parameters are not known

TABLE 4

Basis	b^*	x_1	x_2	x_3	x_4	x_5	x_6
x_4	480	2	1	3	1	0	0
x_5	400	4	2	2	0	1	0
x_6	50	0	1	0	0	0	1

TABLE 5

Basis	b''	x_1	x_2	x_3	x_4	x_5	x_6
x_3	140	0	0	1	$\frac{1}{2}$	$-\frac{1}{4}$	0
x_2	60	2	1	0	$-\frac{1}{2}$	$\frac{1}{4}$	0
x_6	−10	−2	0	0	$\frac{1}{2}$	$-\frac{3}{4}$	1

TABLE 6

		c_j^*	25	20	15	0	0	0	$-M$
c_i^*	Basis		x_1	x_2	x_3	x_4	x_5	x_6	x_7
15	x_3	140	0	0	1	$\frac{1}{2}$	$-\frac{1}{4}$	0	0
20	x_2	60	2	1	0	$-\frac{1}{2}$	$\frac{1}{4}$	0	0
$-M$	x_7	10	2	0	0	$-\frac{1}{2}$	$\frac{3}{4}$	−1	1
		$3300-10M$	$40-2M$	20	15	$\frac{M-5}{2}$	$\frac{45-3M}{4}$	M	$-M$
			$2M-15$	0	0	$\frac{5-M}{2}$	$\frac{3M-45}{4}$	$-M$	0

TABLE 7

		c_j^*	25	20	15	0	0	0	$-M$
c_i^*	Basis		x_1	x_2	x_3	x_4	x_5	x_6	x_7
15	x_3	140	0	0	1	$\frac{1}{2}$	$-\frac{1}{4}$	0	0
20	x_2	50	0	1	0	0	0	1	−1
25	x_1	5	1	0	0	$-\frac{1}{2}$	$\frac{3}{4}$	$-\frac{1}{2}$	$\frac{1}{2}$
		3225	25	20	15	$\frac{5}{4}$	$\frac{45}{8}$	$\frac{15}{2}$	$-\frac{15}{2}$
			0	0	0	$-\frac{5}{4}$	$-\frac{45}{8}$	$-\frac{15}{2}$	$-M+\frac{15}{2}$

exactly, it will facilitate a more realistic appraisal of the current operation.

MATHEMATICAL DEVELOPMENT

Consider the columns $j \in B'$ in the final tableau. Rearrange them to form an identity matrix. Let the corresponding columns $j \in B'$ in the initial tableau also be simultaneously rearranged in the same order. We will denote the $m \times m$ matrix thus obtained by $\boldsymbol{A}$. It can be shown that the matrix $\boldsymbol{A}^{-1}$, defined at Step 1 of the algorithm 1a, is the inverse matrix of $\boldsymbol{A}$. Further, it can be shown that every column in the body of the final tableau can be obtained by premultiplying the corresponding column in the initial tableau by $\boldsymbol{A}^{-1}$, i.e., if we define the $m \times 1$ column matrix containing the elements b_i by $\boldsymbol{b}$, and the columns with elements a_{ij} by $\boldsymbol{a}_j$, $j = 1, \cdots, m+n$, we have:

$$\boldsymbol{b}' = \boldsymbol{A}^{-1}\boldsymbol{b}, \text{ and}$$

$$\boldsymbol{a}_j' = \boldsymbol{A}^{-1}\boldsymbol{a}_j, \qquad j = 1, \cdots, m+n.$$

Now consider the matrix $\boldsymbol{A}$. Let one or more of its elements a_{ij} be changed by Δa_{ij}. We will denote this new matrix with elements $a_{ij}^* = a_{ij} + \Delta a_{ij}$ ($i \in B$ and $j \in B'$) by $\boldsymbol{A}^*$. Further, we will denote the columns of the new initial tableau with elements a_{ij}^* by $\boldsymbol{a}_j^*$, and the column with elements $b_i^* = b_i + \Delta b_i$ by $\boldsymbol{b}^*$. It is clear that the simplex tableau with basis variables x_i, $i \in B'$, can be obtained by premultiplying the columns $\boldsymbol{b}^*$ and $\boldsymbol{a}_j^*$ by $\boldsymbol{A}^{*-1}$. We will now proceed to show how the matrix $\boldsymbol{A}^{*-1}$ can be formed.

From the study presented in (5) it will be noticed that changing the constants $a_{ij} \in S_{a'}$, b_i or c_j does not affect the matrices $\boldsymbol{A}$ or $\boldsymbol{A}^{-1}$. We will now study the changes necessary in the elements of the final tableau (which contains $\boldsymbol{A}^{-1}$) because of a change of Δa_{IJ} in an element

$a_{IJ} \in S_a$. Consider the elements of the final tableau in a column $j \neq J$. Following the same line of argument as in the proof of Algorithm 3a in (5) it can be shown that the change necessary in the elements (in column $j \neq J$) of the final tableau consequent to a change in a_{IJ} is given by:

$$\Delta a_{ij}' = a_{iI}' \sigma_{IJ} a_{Jj}', \qquad i \in B', j \neq J, \quad \text{Eq. 5.}$$

where

$$\sigma_{IJ} = -\frac{\Delta a_{IJ}}{1 + \Delta a_{IJ} a_{JI}'}$$

Now consider the initial tableau. We will denote the matrix A and the column J in the initial tableau, with one element a_{IJ} in each changed to a_{IJ}^*, by $\bar{A}$ and $\bar{a}_J$ respectively. The column matrix of the corresponding changes $\Delta a_{iJ}'$ in the elements in column J of the final tableau is given by:

$$\hat{a}_J - a_J' = [\bar{A}^{-1} \bar{a}_J] - [A^{-1} a_J], \qquad \text{Eq. 6.}$$

But, from reference (5) we have:

$$\bar{A}^{-1} = [I + A^{-1} \sigma_{IJ} E] A^{-1},$$

where σ_{IJ} is as defined above, E is an $m \times m$ matrix with a unit element at row I and column J and zero elsewhere, and I is an identity matrix. If we now let $\bar{a}_J = a_J + E' \Delta a_{IJ}$, where E' is an $m \times 1$ matrix with a unit element at row I and zero elsewhere, and substitute in Eq. 6., we get:

$$\hat{a}_J - a_J' = [A^{-1} \sigma_{IJ} E] a_J' + [I + A^{-1} \sigma_{IJ} E] A^{-1} E' \Delta a_{IJ}, \qquad \text{Eq. 7.}$$

since $A^{-1} a_J = a_J'$. It can be shown that $A^{-1} \sigma_{IJ} E a_J'$ is an $m \times 1$ column matrix with elements $a_{iI}' \sigma_{IJ} a_{JJ}' = a_{iI}' \sigma_{IJ}$ (since $a_{JJ}' = 1$), and $A^{-1} E' \Delta a_{IJ}$ is an $m \times 1$ column matrix with elements $a_{iI}' \Delta a_{IJ}$. Further, $A^{-1} \sigma_{IJ} E$ is an $m \times m$ matrix with elements p_{ij} given by:

$$p_{ij} = \begin{cases} a_{iI}' \sigma_{IJ}, & j = J \\ 0, & j \neq J. \end{cases}$$

Hence, it can easily be shown that Eq. 7. can be written as:

$$\Delta a_{iJ}' = a_{iI}' \sigma_{IJ} + a_{iI}' \Delta a_{IJ} + a_{iI}' \sigma_{IJ} a_{JI}' \Delta a_{IJ}, \qquad i \in B',$$
$$= 0 \text{ by substituting for } \sigma_{IJ}.$$

But from Eq. 5. $\Delta a_{ij}' = 0$ for $j \in B'$ and $j \neq J$ since $a_{Jj}' = 0$ in this case. Hence, we have:

$$\Delta a_{ij}' = \begin{cases} 0, & i, j \in B' \\ a_{iI}' \sigma_{IJ} a_{Jj}', & i \in B', j \notin B' \end{cases} \qquad \text{Eq. 8.}$$

This equation can be used to find the changes in the elements of A^{-1} due to change in one element of S_a. Therefore, by iteration, when all the elements of S_a are considered the inverse matrix A^{*-1} is obtained.

The tableau obtained at Step 4 of Algorithm 1a, therefore, represents a linear transformation of the set of restricting equations (with the new constants). If we have $b_i'' < 0$ for some $i \in B'$, the non-negativity restriction on the values of the variables is violated. Otherwise, the usual simplex procedure can be used to test the optimality of the solution, and to proceed further if the tableau is not optimal. This completes the proof of Algorithm 1a. Algorthim 1b follows directly from the study presented in (5.)

We now proceed to prove Algorithm 2. The various rows in the body of the tableau obtained by the application of the algorithms given earlier represent a linear transformation of the set of restricting equations. When some b_i'' is negative, multiplying both sides of the equation by -1 gives us a positive value in the column b'' and does not alter the conditions. However, we lose the basis variable in the row as its coefficient is now -1. The basis variable thus lost can be replaced by introducing a dummy variable with coefficient 1 in the equation inwhich it is a basis variable and zero in the remaining equations. A large negative number $-M$ can be introduced as the coefficients of the dummy variables in the criterion function to insure that in the final solution these variables do not remain in the basis (if the changed problem has a feasible solution). The augmented tableau therefore represents the problem with the new constants, and the simplex method can be directly applied until the final solution tableau is obtained.

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JOURNAL OF INDUSTRIAL ENGINEERING
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Industrial Engineering Techniques and Operations Research

by **EUGENE RICHMAN**[1]

Associate Professor, Department of Industrial and Management Engineering, New York University

and **SYLVAIN EHRENFELD**[2]

Associate Professor in Operations Research, New York University

THE Operations Research analyst is interested in all operations, be they industrial, governmental or military. The Industrial Engineer has been interested primarily in industrial operations. During the last half century many techniques have been developed by the Industrial Engineer for the analysis and solution of industrial problems. Many of these techniques can and are being used by Operations Research people for analysis of industrial and other operations. Other techniques which have been developed by the Operations Research analyst are very valuable to the Industrial Engineer.

Regardless of the differences and similarities of these two fields (8), each has benefited the other and the continuing possibilities for future utilization of the efforts of these two groups hold forth great promise. It is the purpose of this paper to present in brief the historical development of the traditional techniques of Industrial Engineering, to show by a simple example the contribution of Operations Research, and briefly to survey some of the other analysis techniques of use to the Industrial Engineer.

DEVELOPMENT OF INDUSTRIAL ENGINEERING TECHNIQUES

FIRST STAGE

The first stage of improvement of industrial operations may be said to be the pre-Taylor era; the period of time from the beginning of the Industrial Revolution to about 1881 when Frederick W. Taylor obtained authorization from the Midvale Steel Company "to make a series of careful scientific experiments to find out how quickly the various kinds of work that went into the shop ought to be done" (13). The principle of interchangeability had been introduced by Whitney about 1800 and most of the basic machine tools were being used. Nevertheless, most industrial operations were "man-paced" or only partially controlled by a machine cycle. Production was primarily of a job-lot nature. Payment was chiefly on the basis of a day rate. The position of organized labor during this period may, perhaps, best be characterized as weak. Improvements of industrial operations were made in an arbitrary manner, on the basis of little more than hunches, opinions or the intuition of employers. In short there was no organized, workable basis for the study and improvement of industrial operations, and only the simplest descriptive means were employed for these purposes.

SECOND STAGE

The second stage was the period of early "Scientific Management," 1881 to 1931—Frederick W. Taylor to W. A. Shewhart. This period was marked by the rapid growth of descriptive and simple analytical methods for the study of industrial operations. The organized labor movement gained momentum. Industry began its giant growth and was marked by both increasing complexity and specialization. Time and motion study techniques were ushered in by the work of Frederick Taylor, Frank Gilbreth, Carl Barth, Harrington Emerson and their contemporaries (6). Industrial organizations became interested in work methods, time study, wage payment plans, production planning and control and elementary cost controls. Charting techniques employing the use of such tools as the Operation Process Chart, the Flow Process Chart, Man-Machine Charts, Operator Process Charts (right hand-left hand charts), simple layout charts, Gantt charts, Break-Even Charts and the like were developed (4). On the whole these tools were visual, descriptive and allowed for analysis primarily of a qualitative nature. A good beginning was made, however, toward the use of quantitative analytical methods with the development of economic lot size equations, materials handling equations, standard data formula construction, and the development of engineering economic analysis.

[1] On leave from University of Southern California to participate in the NYU-ICA Industrial Management and Executive Development Project in Israel.

[2] At present participating in the NYU-ICA Industrial Management and Executive Development Project in Israel.

THIRD STAGE

The next period from 1931 until the beginning of World War II saw an increasing awareness of costs and the rapid growth of the use of statistical and analytical tools for both the planning and control phases of industrial operations. Significant achievements were the development of statistical quality control, work sampling methods, and quantitative methods for inventory, production and cost controls.

The introduction of statistical quality control in particular, was a tremendous step forward both for Industrial Engineering and for Operations Research. It incorporated once and for all the utilization of the concept of probabilistic behaviorism as a device of problem conceptualization, analysis and control. Statistical quality control is concerned primarily with determining if an industrial process is behaving as it should be expected to behave if nothing significant has occurred to change the process. The beginning of the use of probability theory and statistics for quality control has expanded so that this concept has pervaded the entire field of Industrial Engineering and Operations Research. Its eventual importance for industrial operations is yet to be realized (12).

FOURTH STAGE

Finally, the present era, from World War II until today, has witnessed tremendous strides in the ability to handle uncertainty in a more quantitative manner. This has come about because of the joint advances in Industrial Engineering and Operations Research and Analysis (3).

The first organized Operations Research teams were persons assigned to study various aspects of military operations during World War II. Application of the techniques used and developed during the war to industrial operations was but a natural extension of the utility of Operations Research. The scientific background of most of the men making up the operational analysis and research teams led to the increasing use and development of mathematical models, in addition to the practical models already available. One of the greatest contributions of Operations Research to the solution of problems of industrial operations was the joint appreciation of what mathematics had to offer as a basis for viewing and solving operational problems, coupled with the rapid development of mathematical methods resulting from their need. Some of the techniques which have found wide acceptance are the use of allocation or linear programming models, queueing models, replacement or renewal theory, and Monte Carlo techniques. These and other recently developed techniques are being used today by both the Industrial Engineer and the Operations Researcher. A significant concurrent event has been the tremendous improvement and development of a variety of data processing mechanisms which afford rapid solution to problems which can be suitably programmed.

The basic developments, concerning industrial operations in Industrial Engineering and Operations Research, which have brought both of these fields to their present state, thus appear to be:

1. The increasing awareness of and concern with costs involved in industrial operations.
2. The increasing ability over the years to handle uncertainty in a quantitative manner. Even the human factor, the most uncertain element in production, is becoming somewhat amenable to analysis by the newer techniques, models and data processing means.

An example to illustrate the growth of the ability to solve problems of industrial operations has been chosen in the area of office work. This choice was made because the office is, after all, part of the industrial concern, and also because this area of endeavor involves to a large extent the human factor, which until recent time, has been treated only qualitatively.

EXAMPLE

Let us consider the following oversimplified situation: An office has two girls. The only work involved is typing and answering the phone. We are interested in finding out if the office is properly run. How would this problem be approached in each of the stages of the development of industrial techniques? We begin by looking at the Second Stage since the First Stage predates this type of problem.

Second Stage—Early "Scientific Management," 1881-1931

During this period, if one wanted to know how well the office was run, it was largely a matter of how one "felt" about it. There were no known standards of performance for office work. The manager was either satisfied that the work was done properly or concerned that it was not. Of course, if there were backlogs of typing and vocally dissatisfied "clients," or if persons complained that their phone calls were unanswered, it became apparent that "something was wrong." Whether the problem resulted from too much of a work load or because of incapable office help was for the most part a vague uncertainty. If the manager wished to ascertain how well the office was run, he was faced with three possibilities:

1. The office was overstaffed.
2. The office was properly staffed.
3. The office was understaffed.

If overstaffed, the following alternatives exist:

a. Fire one girl (which one?).
b. Fire both girls and rehire one.

If properly staffed, these are the alternatives:

a. Keep the same girls.
b. Fire one girl (which one?), rehire one girl.
c. Fire both girls, rehire two girls.

If understaffed, the alternatives are:

a. Hire one more girl.
b. Fire one girl (which one?) and hire two girls.
c. Fire two girls and hire three girls.

Thus, even in this simplified example, it is interesting to note that there are eleven alternatives. The problem would be much more realistic but considerably more complicated if both the office inputs, allocations and the work methods, layout of office, etc., could be improved.

Whichever alternative was chosen, it could then be given the test of time and the manager was either satisfied that "all was well" or he could hire a fourth girl, replace any one of the three girls, etc. The criterion for "all being well" was vague. The cost of the operation was known only to the extent of comprising the day wages of each girl. Of course, during this period, time and motion study was being used for production workers in the factory, but this technique was believed to be mainly applicable to "productive" work.

Third Stage—1931 to 1940

During this period the office problem might have been tackled with the technique known today as "Work Sampling" (2). Work Sampling is a means of estimating a great deal about the nature of a work situation and the effectiveness of the workers, by means of analyzing a large number of extremely short random observations of the work in progress. It is based on probability theory and requires the use of some statistical techniques such as an adoption of the control chart technique developed by Shewhart.

To analyze this office job the office girls' activities might be categorized as:

1. Answering phone.
2. Typing.
3. Idle.

A number of observations would be taken at random times which have been previously selected, to determine the frequency of occurrence of each category for each girl.

The number of observations to be taken would be based on the precision interval and the confidence level desired for the estimate and could be calculated statistically. Then, in order to check the stability of the system (i.e. the functioning of the office), a work sampling control chart could be made, similar to the one shown in Figure 1. Actually, a separate chart might be made for each girl.

From such an analysis, a great deal could be found out, assuming a statistically stable system existed. A high percentage of idle time might indicate that the girls were not supplied with enough work. Although some idle time is to be expected, an idle time figure of 75% to 80% might indicate that only one girl was needed, provided that there was no apparent backlog of typing in evidence. An extremely low idle time percentage plus a backlog of unfinished typing would verify the need

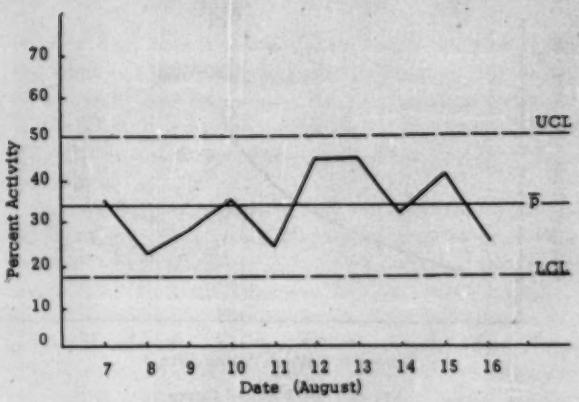

Fig. 1. Typical Work Sampling Control Chart.

for additional help. Analysis of the data would show within limits what percentage of the time the girls were occupied at the designated activities. It would show if one girl were more busy or idle than the other and if either girl spent more time typing than phoning. Thus, the study could indicate the relative efficiency of each girl and also allow the manager to a large extent to ascertain whether the girls were dividing the work in the prescribed manner.

The Present Era

The Work Sampling technique previously described might also be effectively used at the present time. However, there are a number of limitations inherent in this technique as well as limitations in the amount of information the technique makes available for the analyst. It is difficult to decide over how long a period the work sampling study should be taken. It is to be expected that some idle time is necessary, but how much? This is difficult to determine. The reason for the unavoidable idle time is that both the input to the office (of typing and of phone calls) is not regular (i.e. not deterministic). Because these inputs are irregular, it can happen due to chance that at any moment there may be no backlog of work or there may be a sudden rush of work. Also, the time required to do a unit job will vary. That is, it does not require the same time to answer the phone each time it rings, nor does it take the same time to type a page of written material. Another interesting characteristic of the problem is that the phone should be answered immediately, but typing material can be put aside until a later time.

The heart of the matter is the question of how much idle time is to be expected due to the nature of the input pattern of the work and the service time required to do the work. By increasing the number of girls the idle time could be reduced, but at a greater cost. The problem is to increase the cost of the operation only to the extent where the savings brought about are still greater than the increased cost.

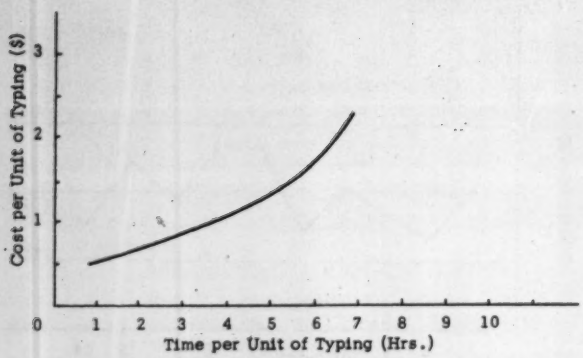

FIG. 2. Cost Penalty Curve.

If it can be determined that the demand for services, that is the input of typing and phone calls, has a stable statistical character, then queueing theory can be used (10). Queueing theory, which is a part of probability theory, can be used to show what the effect of changing the number of office helpers will be in terms of reducing idle time. This in turn can be translated into dollars. *Thus, this technique provides a criterion which can be checked quantitatively.* The mathematics for various types of inputs and outputs have been worked out in recent years and charts and tables are available for some of these cases. Unfortunately, however, there are many cases of interest for which the mathematics have not been completely worked out. Work sampling alone provided information about the present idle time of the present situation. *A queueing model could then be used to predict the percent of idle time with a different number of girls.* Queueing theory could not be used with confidence until a check of its applicability is made (1). To do this, a statistical test of the distribution of intervals between typing and phone inputs could be made to see how close the actual distribution approached the distribution assumed in the model.

Another technique which could be applied to this problem with much advantage is the Monte Carlo method (9). This method could be used even where queueing theory would not apply. If the inputs were so complex that they either could not be formulated analytically or resulted in analytical models which are too cumbersome to manipulate economically, Monte Carlo methods could be used as long as:

1. A statistically stable system exists.
2. The important parameters of the problem are known and the cost functions involved can be stated.

In other words, to use this problem solving technique, it is necessary to be able to express the problem in a more quantitative fashion. While this may be more difficult to do, the enforced thinking about the problem leads to results which are more refined and which reduce the uncertainties about the operation to a greater degree than was possible before.

To present the Monte Carlo technique in a simple fashion for the office problem stated, we might start by considering only the following two alternatives:

1. Hire one more girl.
2. Remain the same.

The following assumptions could be made:

1. All variables are assumed to be fixed except the number of girls as previously stated.
2. All the girls in question are assumed to have the same capabilities and would be hired at the same salary.
3. There is to be an equal division of the work load and both girls type and answer the phone.
4. All typing has the same priority.

It is necessary then to specify the rules of the office, the cost functions and the nature of uncertainties as follows:

Rules of the office

1. Phone Calls
   a. If both girls are idle, they are to take turns answering the phone.
   b. If one girl is typing, the other girl is to answer the phone.
   c. If both girls are busy typing, they are to take turns answering the phone.
2. Typing—The units of typing are to be pooled and shared equally between the girls.
3. Idle time—Girls are permitted to read or knit during unavoidable idle time.

Cost functions

1. The salary of each girl is assumed to be the same. Thus, this cost varies only with the number of girls hired.
2. If a unit of typing is not done on schedule, there is, of course, a cost penalty incurred. It is necessary to determine the exact nature of this cost function. A plot of this type of function is shown in Figure 2.
3. It is assumed that, since the phone is to be answered immediately and the typing held up, if interrupted, during phone calls, that there will be no cost penalty due to phone calls unanswered.

Nature of Uncertainties

1. Variations in inputs and amounts of typing material can be determined from observations and plotted as shown in Figure 3.

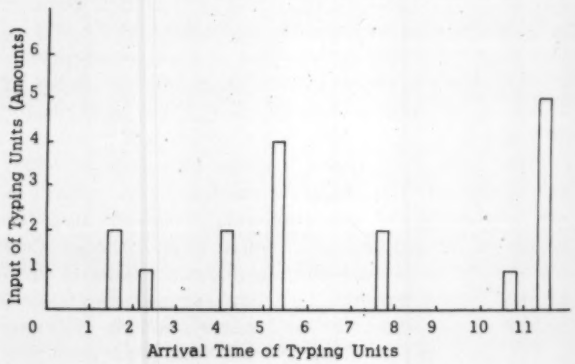

FIG. 3. Quantity and Arrival Pattern for Typing Units.

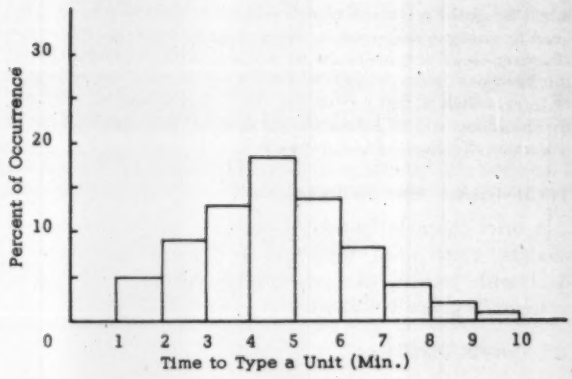

FIG. 4. Variation in Service Time for Typing.

Note that in Figure 3 the number of units of incoming typing is shown by the heights of the bars and the time of arriyal of these batches is shown by the numbers 1, 2, 3, etc., along the horizontal axis. To use the Monte Carlo technique it is only necessary that the arrival patterns and quantities variation have some specific stable statistical character.

2. The variation in service time for typing can be determined by observation and can be shown as in Figure 4.

3. In a similar manner input variation and length of time for phone conversations can be specified. Assume again that a specific stable statistical pattern is found.

Application of Monte Carlo Technique

It is apparent that the basic criterion in this problem is balancing the cost of the extra girl against the reduced cost penalty imposed when material is tied up waiting to be typed. Thus, it is necessary to find the cost per unit of typing with either two girls or three girls, taking all variables into account. This is done by simulating typing inputs and quantities, and phone call inputs and service time variation in such a way that they have the same statistical character as described in the problem. This simulation may be done to correspond to the functioning of the office in a typical manner for as long a period of time as is considered necessary (i.e. a week, month or year) to give results of which one can be confident. Again, confidence intervals can be determined statistically. This simulation is done using the rules of the office as described and the statistical information as given. Thus, the history generated will have the same statistical character as indicated in the Figures previously given. We then observe the simulated history for the desired period of time in terms of work loads, avoidable and unavoidable idle times, etc. With this information computations can be made for cost with two or three girls and the proper choice made. Figure 5 shows the way the data derived from simulation might be plotted. Of great interest is the fact that this problem can be set up in such a manner that it can be done on a computer. This problem which was chosen for its simplicity involves a relatively low cost. For problems involving a larger number of workers or very high cost it is often most worth while to spend the time and effort to set up the problem so that it can be solved by this technique. Furthermore, once the problem is set up it is easily possible to perform computations for various cost assumptions and to see how sensitive the decision is.

In the office problem given, only the use of the technique of Work Sampling was presented as a problem solving method which might have been used during the Third Stage (1931 to 1940). Likewise, only the additional techniques of Queueing Theory and Monte Carlo were presented as methods which could be used today. Obviously other problem solving techniques cited during the earlier discussion could have been used for this type of problem or for other problems which have been encountered during the periods mentioned.

The techniques selected for discussion were chosen so as to show the trend toward the development and refinement of techniques used to solve problems. It is hoped that the simple example given will help to indicate the greater breadth and complexity of the problem solving philosophy and techniques of today as compared to those of the past.

During World War II scientists were successfully utilized in the study of military operations (11). This experience in war time has stimulated similar activities in industry and other operational contexts. Thus, in the years since the war, Operations Research has had a rapid development. The approach has in the main been an operational and scientific one. The interest and concern is with operations of all kinds, industrial, governmental or military. An operation is used here in the sense of an activity where there is repetitive action. A battalion of soldiers doing its assigned job, an assembly line or a sales organization is more than a collection of men and machines; it is an activity, a pattern of operation. These operations can often be studied, their regularities investigated, and sometimes they can be effectively modified and improved.

DEVELOPMENTS

Experience with operational problems has highlighted certain features and stimulated certain developments, such as:

a. An increased awareness that a number of *general characteristics in operating systems repeat themselves in a variety of different contexts* (5). For example, one characteristic operational problem is, that involving *flow*, e g. flow of aircraft in and out

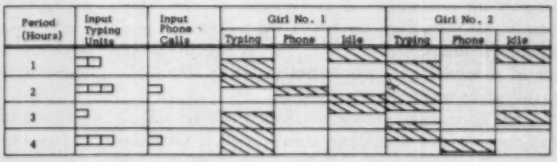

FIG. 5. Simulated Monte Carlo History.

of an airport, of ships in and out of a harbor, of merchandise in and out of a store, of items in and out of a warehouse, of machines in and out of a maintenance repair shop. The operational feature, which the foregoing have in common, is a sequence of *units* arrive at some *facility* which services each unit and eventually *discharges* it. The problem often is that the units arrive in some uncertain pattern and service time at the facility may be variable. The variables which should be studied *quantitatively* are the effect of these variations on waiting times for these units, queue length, etc., as a function of such things as size of service facility and possible control over some of the uncertain behavior of arrival and service. Another type of problem is that of *allocation*, e.g. how to allocate production resources of a plant to different items of manufacture, to allocate time of facilities of various types to assigned tasks, etc. Allocation problems usually arise when: 1. there are a number of tasks to be carried out and there are alternative ways of doing them, and 2. facilities are not available for carrying out each task in the most effective way. The problem, then, is how to pair tasks and resources (material and/or facilities) so as to maximize effectiveness.

b. An increased awareness of the *interdependence of the different components of operating systems*, and the importance of studying these interrelationships quantitatively. In the allocation of limited resources to various components of the system, this feature of interdependence is clear, since resources used for one component restrict the possible use of resources for other components. A particularly striking set of cases of the importance of interrelationships are complex systems whose operation depends on the successful functioning of a large number of components. For example, if an operating system has 50 components, each having a reliability of 99%, then the over-all operating reliability of the system is 60%. For 200 components the reliability is only 15% (7).

c. An increasing awareness of the need for an explicit, *quantitative treatment of the effect of uncertainties in various variables of the operating system*. An example of this is the study of the effect of different inventory policies in the light of uncertainties of demand and time to replenish stock (14). A case in point is the awareness of the need for buffer stock, but the economic amount of such stock requires an explicit and quantitative treatment of the uncertainties of the situation. The economic amount of buffer stock would balance cost of carrying stock as against the costs of not having stock when needed. Another example is the study of the economic assignment of the number of repairmen in a repair crew to a number of machines, as well as the method of functioning for the repair crew. Obviously, the successful solution of this problem depends, here as before, on the explicit quantitative treatment of uncertainties such as breakdown characteristics of the machines and the variation of time needed for repair. The economic assignment of machines to repairmen would balance cost of idle time of machines versus cost of idle time of repairmen. It is interesting to note in this connection that idle time of workers is in some cases an inevitable by-product of the economic operation of the system and must be taken into account. In problems of operating systems with several components and uncertainties, intuition is sometimes a poor guide. Moreover, intuition most often cannot provide a quantitative basis for action. Consider your intuition on this: There are 25 persons in a group. What are the chances that at least two have the same birthday? Many people without an awareness of the effects of uncertainty would say, "small." In fact, they are better than even. If there are sixty in a group, the chances are 99.4%. This is not to say that intuition is not of immense value, but that intuition should be coupled with quantitative methods.

d. An increasing *use of mathematical models to describe and study operations*. A mathematical model is a symbolic representation of the system under study. Because of the recurrence of certain types of systems, Operations Research has developed what might be called prototype models which are applicable to the frequently encountered systems. Most of these models express the effectiveness of the operation as a function of characteristics of the operation, some subject to control, others not. The objective of these models is, first, to describe the present system and, second, to determine which values of the control variables will yield maximum effectiveness of the system.

TECHNIQUES AND MODELS

A brief characterization of some of the techniques and models, which have developed in order to describe and deal with certain characteristic problems in operating systems, is given as follows:

ALLOCATION PROBLEMS

The techniques developed for allocation problems are sometimes called linear programming, input-output analysis, or simply programming. Examples of problems which have been solved by allocation techniques are:

1. *Transportation problem*—Several sources supply a certain number of outlets. Some differences exist in the manufacturing costs, and the cost of shipment varies for the different source-outlet routes. Each source has a certain maximum capacity restriction per month. Furthermore, each outlet has a fixed requirement per month. How much should each source produce, and where should the outlets get their requirements

2. *Production scheduling*—How should production be scheduled so as to meet a fluctuating demand in time? The problem here is to balance the production costs versus inventory costs.

3. *Machine assignment problems*—A specific number of machines are available, and a specific number of tasks need to be performed. Assume there is a measure of the productivity of the various machines for doing the various tasks. The problem is—how should the machines be assigned to the tasks in order to maximize the over-all productivity. It is of interest to note that this technique has been applied to the assigning of personnel to job categories.

The foregoing examples give only a minute glimpse of the variety of applications of the technique. The optimum allocation of limited resources is certainly a recurrent, important problem in a variety of situations.

FLOW PROBLEMS

As previously described, flow, or as sometimes called, waiting lines or queueing problems arise when units arrive at a service point for service, and either these units are kept waiting or some of the facilities are idle. In order to specify the operation, a queueing discipline must be prescribed. That is the rule of the order of servicing incoming units. An example of such a rule is, first come—first served. In certain cases priorities exist and in other cases part of the problem is to decide on an optimum priority system. The objective then is to obtain an optimum balance between:

1. The costs associated with the waiting of the units requiring service.
2. The costs associated with providing the service required.

The units arriving for service may be customers, orders, trucks, trains or production lots, etc. The servicing units

may be sales girls, stock room clerks, unloading docks, machine tools, etc. Scheduling or flow problems can be grouped into three classes, depending on what the control variables are:

1. *The rate of arrival of units is not subject to control, but servicing facilities are.* The problem is to determine how many service units will minimize the sum of the waiting and operating costs. Examples of such problems are: the determination of optimum amount of iron ore unloading equipment required at a dock, the optimum number of workers in a repair crew, or the number of busses required on a bus route.

2. *The amount of facilities is fixed (not subject to control), but the arrivals are subject to control.* The problem is to determine how the arrivals should be scheduled so as to minimize the relevant costs. Examples of such problems are: scheduling the arrival of aircraft at an airfield, setting up an appointment system in a hospital, or devising rules of preventive maintenance.

3. *Both the facilities and arrivals are subject to control.* The problem is to determine what facilities should be provided and how the arrivals should be scheduled. An example of this is the contracting of materials and services in the construction of a plant.

Much work has been done in Queueing Theory, and results are available for a variety of assumptions concerning arrival time uncertainties, servicing time uncertainties and priority rules (10).

REPLACEMENT (OR RENEWAL) PROBLEMS

The costs incurred in such problems depend on the nature of the units involved. These units fall into two classes:

1. Units that degenerate, that is, units whose efficiency decreases with use and/or passage of time. The problem here is to balance the cost of new equipment against the gains in efficiency. It is worth noting that replacement rules existed before the development of this theory but they assumed perfect knowledge of the future. Replacement theory as developed in Operations Research takes into account the fact that predictions are involved and that these predictions are subject to error.

2. Units that do not degenerate; such units maintain a relatively constant level of efficiency until they fail or "die." Electric light bulbs are an example of such units. The problem here arises out of alternative ways of replacement. One possible policy is to replace a unit only when it has failed. In such a policy the cost of the units consumed is minimized, but the cost of replacement is high because the bulbs are replaced one at a time. On the other hand, if all units are replaced simultaneously at the time of the first failure, cost of the units are high because of low utilization. However, the cost of replacement may be reduced. An optimum policy may lie between these extremes. The problem is to find out where the optimum lies. Replacement theory has been applied to establishing replacement policy relative to light bulbs and electron tubes (5).

MONTE CARLO TECHNIQUE

A recurrent feature of many operating systems is:

1. Complexity of the system with regard to the statistical character of uncertainties.

2. Prohibitive effects of interfering with the operation of the system.

A technique has been developed to study operations having the foregoing features. The method consists of observing the statistical character of the variables and to simulate history for the system where the variables have the observed statistical character. The effect of various improvements on the operation can then be measured by seeing the effect on the system during this simulated operational history.

There have been many applications of this technique, such as: finding optimum maintenance policies, inventory policies or solving complicated flow problems in production networks and telephone traffic (9). It is clear that simulation techniques will be of increasing value for the study of complex industrial situations.

SUMMARY

In the development of the philosophy and application of techniques for the analysis, design and improvement of operations, important contributions have been made by the Industrial Engineer and the Operations Researcher. Each has contributed and each can derive great benefit from the past and present efforts of the other.

The trend over the years has been toward an increasing awareness of the costs involved in carrying on operations as well as toward an increasing ability to handle uncertainty in a more quantitative manner. It can be expected that the combination of Industrial Engineering techniques and Operations Research will lead to an ever-increasing ability to deal with problem solving in a more effective manner.

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Estimating Load Requirements in a Job Shop

by **FRANCIS L. CANNING**

Procedures Development and Application, Power Department, Sharon Transformer Division, Westinghouse Electric Corporation

IN A job shop, where many different varieties of a basic product are produced to customer specifications, we are confronted with a problem that lies at the foundation of many other problems and that can briefly be stated as follows: Given a manufacturing load in terms of units of unique apparatus in several broad product classifications or codes, what man-hour requirement is necessary in each shop section to meet the scheduled load? Since we are not manufacturing a line of standard products, we cannot know the actual sectional man-hour requirements at the time an order is entered. Consequently, we must obtain a reliable *estimate* of the man-hour requirements of our individual orders and total load, several months in advance of production, in order to realistically date new orders as a function of uncommitted capacity, to reschedule existing orders, to plan overtime and undertime, to adjust the size of the work force, and to subcontract segments of the load if necessary.

Empirical averages of sectional man-hour requirements for each broad product classification do not provide the solution to our problem because of the wide variability of these times within each code, and the "actual" man-hour requirements as determined from standard data are generally not available far enough in advance of production to enable us to take intelligent action appropriate to the load. The load requirements, therefore, must be obtained in some other fashion. The method selected,[1] and successfully applied within our organization, can be termed Multiple Linear Estimation.

The theory of Multiple Linear Estimation (usually under the subject heading, "Multiple Regression") is adequately covered in the literature (3), (5), (6), (7), but we will introduce in the next selection several concepts necessary to illustrate its application to a specific load estimation problem. The problem we shall discuss will be that of estimating the time required to build up the laminations that form the core of a shell-type power transformer (Figure 1).

METHOD OF SOLUTION

THEORY

In a Multiple Linear Estimation problem we attempt to estimate a dependent variable, Y, by a linear function of several other variables, the predictors, $X_1, X_2, \ldots, X_p$. The linear estimating function is usually expressed as

$$\hat{Y} = C_0X_0 + C_1X_1 + C_2X_2 + \cdots + C_pX_p = \sum_{i=0}^{p} C_iX_i \qquad \text{Eq. 1.}$$

where $\hat{Y}$ is the estimated value of Y, the X_i are selected predictors,[2] and the C_i are constants determined from n $(n > p)$ different sets of homogeneous data by the Method of Least Squares.

Presumably, N $(N \geqslant p)$ variables are intuitively selected as potential predictors, and their simple correlation coefficients with the dependent variable are calculated from a random sample of data sets. Assuming that more than one of the X_i are required to achieve the desired degree of predictive accuracy, it is then necessary (from one point of view) to calculate all of the possible multiple correlation coefficients of Y on the X_i—the object being to discover a smallest combination of the X_i having a multiple correlation coefficient that is not significantly different from the multiple correlation coefficient of Y on all the X_i taken together, $R_{Y.12\ldots N}$.

To obtain the $C(N, N) + (N, N-1) + C(N, N-2) + \cdots + C(N, 2)$

$= \sum_{r=2}^{N} C(N, r) = \sum_{r=0}^{N} C(N, r) - (N+1)$

$= 2^N - (N+1)$ multiple correlation

1. Calculate C(N,2) intercorrelation coefficients.
2. Evaluate C(N,N) determinants of order N + 1, C(N,N − 1) determinants of order N, C(N,N − 2) determinants of order N − 1, ..., and C(N,2) determinants of order 3.
3. Evaluate C(N,N) determinants of order N, C(N,N − 1) determinants of order N − 1, C(N,N − 2) determinants of order N − 2, ..., and C(N,2) determinants of order 2.

Computationally, we would calculate $R_{Y.12\ldots N}$, and then search the variable combinations in ascending order for a multiple correlation coefficient not significantly different

[1] The author wishes to acknowledge the contribution of M. J. Cooke, Sharon Westinghouse, who first suggested that some type of correlation analysis might be applicable to the problem.

[2] X_0 is a dummy variable which always assumes the valve unity.

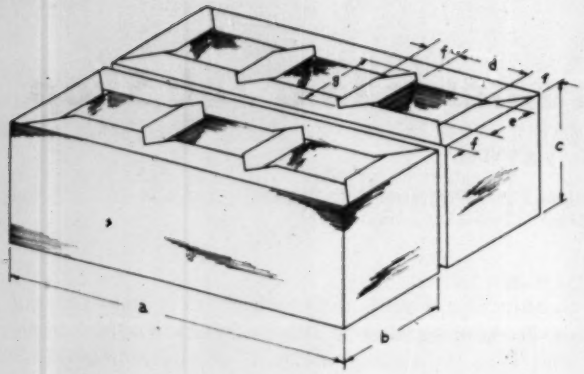

FIG. 1

from $R_{Y.12\ldots N}$. This would ordinarily decrease the total number of determinant evaluations.

APPLICATION

With the assistance of Industrial Engineering personnel, eight ($N = 8$) physical variables were selected as potential predictors from an engineering document available two months in advance of production. These variables were considered to be linearly related to core-building time (Y), and, with reference to Figure 1, are described below:

X_1 = number of stacks
$X_2 = bf$ = yoke area (in.^{2})
$X_3 = gf$ = short area (in.^{2})
$X_4 = af$ = leg area (in.^{2})
X_5 = total weight of iron (k lbs.)
$X_6 = cde = \frac{1}{6}$ opening volume (k in.^{3})
$X_7 = abc = \frac{1}{2}$ core volume (k in.^{3})
$X_8 = c$ = stack height (in.)

The simple correlation coefficients with the dependent variable were calculated from a random sample of 50 recent data sets, and these are listed in Table 1.

TABLE 1

$r_1 = .48$	$r_5 = .95$
$r_2 = .89$	$r_6 = .78$
$r_3 = .95$	$r_7 = .79$
$r_4 = .91$	$r_8 = .83$

Next, as a step in determining which (if any) of the eight variables were redundant, the $C(8,2)$ intercorrelation coefficients were calculated from the 50 data sets mentioned above, and these are listed in Table 2.

To have attempted to find a smallest combination of the eight variables with a multiple correlation coefficient not significantly different from the highest possible multiple correlation coefficient (Y on all the X_i taken together) would have required the calculation of at most 247 multiple correlation coefficients implying the evaluation of a considerable number of high order determinants as shown previously. This method of eliminating redundant variables seemed highly impractical, and, of course, could not be considered where electronic computers are not available. Although such a procedure would be necessary to locate an optimal set of predictors, it is seldom undertaken because of the time and expense involved in the necessary calculations.

TABLE 2

$r_{12} = .56$	$r_{13} = .73$	$r_{14} = .76$	$r_{15} = .71$	$r_{16} = .70$	$r_{17} = .52$	$r_{18} = .25$
	$r_{23} = .93$	$r_{24} = .89$	$r_{25} = .92$	$r_{26} = .60$	$r_{27} = .64$	$r_{28} = .81$
		$r_{34} = .57$	$r_{35} = .58$	$r_{36} = .61$	$r_{37} = .64$	$r_{38} = .66$
			$r_{45} = .97$	$r_{46} = .85$	$r_{47} = .82$	$r_{48} = .69$
				$r_{56} = .82$	$r_{57} = .84$	$r_{58} = .79$
					$r_{67} = .89$	$r_{68} = .53$
						$r_{78} = .69$

Several sub-optimal variable selection procedures are available, and, although having admitted deficiencies, they do produce acceptable approximations within a reasonable amount of computation time. In particular, the author is familiar with two escalator procedures—"forward selection" (4) and "backward elimination" (1)—and both have performed well in this and similar estimation problems. Very generally, "forward selection" will usually select a smaller set of predictors than "backward elimination," but the latter is to be favored in estimation problems because it will always choose a set of predictors with a multiple correlation coefficient that is not significantly different from the highest possible multiple correlation coefficient. Additionally, "backward elimination" provides the user with an exact control on the confidence level at which he wishes to operate.

In the first solution of the estimation problem under discussion, three (X_2, X_4, X_6) of the eight potential predictors were eliminated solely on the basis of relationships among the first-order intercorrelations (2), and the estimating model Eq. 1. became

$$\hat{Y} = C_0 + C_1X_1 + C_3X_3 + C_5X_5 + C_7X_7 + C_8X_8 \quad \text{Eq. 2.}$$

With the predictors selected in this fashion, it was then necessary to determine the C_i ($i = 0,1,3,5,7,8$) in Eq. 2. from n different sets of homogeneous data by the Method of Least Squares. Four hundred[3] sets of unique relationships between core-building time (Y) and the five selected predictors (X_1,X_3,X_5,X_7,X_8) were obtained from the engineering documents of 400 shop orders produced over all product codes. These shop orders were transformers produced from the most recent engineering designs, and whose core-building times were determined from current standard data. The required Least Squares summations and the solution of the Normal Equations

[3] This excessively large sample was gathered in conjunction with other objectives requiring a large amount of historical information. It has been suggested that a good working rule is to choose n to be at least four times the number of variables.

for the C_i were performed in 10 minutes on an IBM 705. The (multiple) correlation coefficient between observed and estimated core-building time was .98. By way of comparison, the "backward elimination" method chose the same variables as above, but the "forward selection" method picked X_1,X_3,X_5,X_8 with a (multiple) correlation coefficient between observed and estimated core-building time of .96.

Testing the initial estimating equation on a sample of 100 current shop orders, 30% of the estimated core-building times were within ±1% of the corresponding actual core-building times, 75% were within ±5%, and maximum error (occurring twice in the 100 estimates) was ±20%.[4] (Such events as design changes and process improvements that led to revisions in standard data would, of course, cause significant departures from this distribution, and a new estimating function would have to be calculated from the modified data.) Under a full schedule the total monthly core-building load requirement has consistently been estimated within ±1%, but under a reduced schedule the percentage error rises slightly because the probability of estimating high or low on a majority of the scheduled units increases as the number of scheduled units decreases.

The elimination of variables on the basis of their first-order intercorrelations, without regard for higher-order intercorrelations, is not a sound procedure, and should be approached with caution. However, since this method and the escalator methods mentioned above have arrived at equivalent results in this and many similar estimation problems, it would appear that higher-order intercorrelations may be safely ignored in this particular type of estimation problem. Certainly this method should not be employed where one is attempting to establish a functional relationship (say, in a chemical process) between one variable and a group of others. The variable selection method described in (2) and the "variance analysis" methods discussed in (3) and (7) lend themselves to manual computation, but it is perhaps best to take advantage of an escalator method where computers are available.

CONCLUDING REMARKS

Generally a multiple linear[5] estimation function will be required for accurate estimates of the load requirement for individual orders, although the total load requirement for a group of orders can be closely estimated from a single strongly correlated variable. Electronic computers are easily programmed to rapidly obtain accurate estimating functions, but where computers are not available a five or six variable function can be practically obtained from 100 data-sets with the aid of a desk calculator.

In the manufacture of power transformers a single estimating equation per section has yielded distributions of percentage error similar to that mentioned previously, but in other types of job-shop manufacture it may often be necessary to obtain more than one estimating function in each section (possibly one for each product code) to achieve an acceptable degree of estimating accuracy. Where the load requirements in two or more sections are highly correlated, the task of gathering data and the mechanics of estimation can be greatly simplified, with little loss in estimating accuracy, by using the same predictors in the estimating functions for those sections. For example, the same predictors used in the core-building load requirement estimating equation were successfully used in the load-estimating equation for the section which produces the laminations required for building the transformer core.

Applying the same type of analysis, accurate load-estimating functions have been developed for all shop sections, and the load requirements in all shop sections for any designed transformer are now estimated from a bank of equations stored in the computer. This presents attractive possibilities in the area of detailed scheduling. Advance knowledge of load requirements combined with sectional capacities, efficiencies, and cycle times will make possible a rudimentary method of scheduling which promises to be superior to current job-shop scheduling practice.

[4] Although variances and confidence limits for the regression coefficients and estimated values of Y for given sets of X's would more accurately describe the estimating function, the expected distribution of percentage error is perhaps the most meaningful description from the Production Manager's viewpoint.

[5] Linear functions, of course, do not always apply. Depending upon the relationships among the variables, polynomial and exponential functions may sometimes be more suitable. Alternatively, transformations may be applied to effect linearity.

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An Unusual Work Sampling Application

by **JOHN A. RITCHEY**

Associate Professor of Industrial Engineering, Purdue University

ALTHOUGH the history of work sampling has been one of ever increasing use and usefulness, this paper shall report on yet a new application of this popular technique. It has become common practice to employ work sampling in factories and offices in order to gain information about people and their jobs as well as about equipment and its utilization. It is not common practice, however, to investigate the work habits of a college faculty, much less to learn of these habits by means of the work sampling technique. Yet this is precisely what has been done in a particular study which the following paragraphs shall report. We shall discover and analyze the activity patterns of one group of engineering teachers in the engineering school of a large university by utilizing the technique of work sampling.

A different article has stressed the actual findings of the study, as well as the possible usefulness of studies of this nature to university administrators (7). Readers who are interested in the academic administration aspects should consult that article. This article, however, will place emphasis upon the technical details of the study and give particular attention to the problems of design and application of work sampling to this unusual situation.

THE SPECIFIC SITUATION

For those who are unfamiliar with the mores of university faculties, perhaps a word of explanation is needed before approaching the work sampling study itself. An expression used to desribe this rather special environment is "academic freedom." It is an expression difficult to define or even to describe, for it means different things to different people, particularly in reference to any specific situation. In general, academic freedom is the permissive atmosphere surrounding the teaching profession that permits the teacher liberty to determine the subject matter he will present to his students, as well as the manner in which he will present it. A beginning teacher may naturally receive more "guidance" from his institution than does a professor of several year's experience; however, academic freedom is extended to both. The difference is merely one of degree, according to what the situation warrants. Naturally there is a difference in interpretation of these terms, and many problems and controversies arise in the academic world when interpretations vary markedly. When academic administrators attempt to "run" their departments in the manner that industrial administrators do, there are agonized cries of "interference with academic freedom," and the wrath of aroused faculty usually forces the administrator to change his tactics.

Since, in the teaching profession, freedom of speech and of press are zealously guarded, and independence of thought and action are valued, a study of faculty activity patterns requires delicate handling.[1] Two basic problems occur. First, teachers may refuse to cooperate in making such a study with the vague idea that it in some way violates their privacy or reveals something they prefer to keep secret. Secondly, their generally independent natures and lack of conformity mean that their work habits are somewhat erratic and unpredictable in general. This is particularly true with reference to time. The only important discipline in connection with time for a college teacher is that he meet his class at a particular hour. Most of his other responsibilities, such as grading papers, conducting research, or preparing lectures, may be discharged at any time of day he wishes. If he prefers to accomplish these matters at midnight instead of during office hours, this is considered to be his business and no one else's. Obviously in preparing a work sampling design this peculiarity requires special consideration. More will be said about this later.

WORK SAMPLING BACKGROUND

Since Tippett (8) introduced the basic concept used in work sampling in 1935, and Morrow (6) wrote on "ratio delay" in 1940, examples of work sampling have become so numerous that there seems little need to review the basic theory. Emphasis is placed on the fact that valid results are obtained only when observations are made at random; we are reminded, also, that the binomial theorem applies inasmuch as we are dealing with an event that can occur in either of two ways—in this case, activity, and lack of activity. When there are many types of activity rather than one, the binomial theorem can still be used by considering the proportion of time spent on one activity as compared to that spent on all other types of activity. The computation is based on the formula for the standard deviation or standard error of the percent-

[1] Some industrialists will point out that their employees also require "delicate handling" and in particular the situation is complicated by unions. The same can be said of the teaching situation depending upon the strength of the American Association of University Professors in any particular school.

age, P, for any given sample size, n, which is

$$\sigma = \sqrt{\frac{P(1-P)}{n}}$$

By proper manipulation of this formula, both before and during a study, one is considerably aided in designing the study as well as ascertaining that the results achieve the desired accuracy level.[2]

The use of work sampling in factory and office has been well documented (2) (5), but three other studies in special situations will be mentioned here because of their relevance to our subject study. These three studies are briefly reviewed inasmuch as they involve professional people rather than factory or office workers.

The first is a work sampling study of the nursing profession reported on by Marion Wright (9). This study was actually a small part of a larger study of nursing designed for the improvement of patient care. The work sampling seems to have made a significant contribution to this accomplishment, for after 29 categories of nurse's activities were studies and the results considered, a number of changes were effected. Prior to the study it was not known which activities required "too much" of a nurse's time and which required "too little."

Another work sampling study of interest is that of a number of executives in a medium size industrial concern conducted by C. L. Brisley (3). During a three to four month period he collected around 10,000 observations using a time interval of 10 minutes. This study was mainly useful in revealing to the executives themselves and the company management how the group spent their time. The categories used to describe their activities are worthy of mention. The six main category headings were: talking, writing, reading, clerical work, miscellaneous, meetings, and absent. Under these main headings were a total of 26 subheadings. For example, the subheadings after "reading" were: published matter, correspondence, and form data. The interesting point is that the listings refer strictly to the activity itself, and give no indication of the purpose or worthwhile nature of the activity. Thus, the reading of published matter might include a technical journal, the morning paper, or a comic book. This design was undoubtedly necessary since the subjects were executives and the observations had to be made from a "safe" and diplomatic distance; however, a design of this nature was not considered to be acceptable for the faculty activity study which is the subject of this paper.

The last study to be reported here concerns the utilization of manpower in the teaching profession in an elementary school situation (4). Twenty-four teachers were involved in the study in which three trained observers made 19,268 total observations in 21 days during a three month period. In evaluating his achievement, the author concludes that work sampling provided an adequate solution to the problem of learning how a teacher spends his time; however, it has limitations inasmuch as the study does not indicate what is successful and/or unsuccessful teaching. This is an important point and should be recognized in any work sampling study. Work sampling provides only facts. It does not draw inferences from these facts nor interpret them in any manner. It is the lot of the administrator to draw conclusions from these facts and to act in whatever manner he feels necessary.

On the surface this study of elementary teachers appears to parallel the subject study of university faculty. There is a difference however, and this is due to the difference in the nature of the two types of teaching jobs. The elementary school teacher is expected to be "on the job" for a full working day, whereas the university teacher has much less rigid time requirements as was pointed out earlier.

ACTIVITY CATEGORIES

The engineering department selected for study is one of several at the university in question. It comprises 20 full-time staff members having the rank of instructor or above, all of whom agreed to cooperate in making the study. The problem was essentially that of learning how these 20 teachers spent their time during a typical semester of 16 weeks duration.

The cataloging of activity categories was a relatively simple matter. Preliminary ideas of categories to be used were gained by merely observing the subjects and by discussing the problem with other engineering faculty members. The preliminary list was then subjected to a short pre-test and revised as necessary. The final list contained 18 classes of activity which were grouped in five main categories as follows: teaching, research, administration, miscellaneous, and personal activity. The complete list is reproduced below:

A. Teaching
   1. In class
   2. Course preparation
   3. Course follow-up (alone) e.g., grading papers
   4. Course follow-up (with others) e.g., discussion with student
B. Research
   1. Individual (alone at desk)
   2. Group discussion, eg., discussing research problem with others
   3. Experimental (in laboratory)
C. Administration
   1. General (alone)
   2. Group discussion
   3. Supervision
   4. Meetings (formal)
   5. Student Counseling
D. Miscellaneous
   1. Entertaining off-campus visitors
   2. Attending meeting off campus
   3. Working on consulting job
   4. Visiting plant

[2] For a good discussion of the use of this formula see (1), Chapter 30.

5. Engaging in activity for personal development
E. Personal Activity

It is readily apparent that these categories actually describe the reason for an activity rather than the activity itself. For example, a staff member who is observed to be reading, may be doing so in connection with a research project, an administrative chore, as part of personal development, in preparation for a class, or simply for personal pleasure. Obviously the mere fact that he is reading has little significance in itself. Therefore, unlike the other studies described earlier, this study attempted to relate observed activity to its purpose rather than to simply report the activity itself.

DESIGN FOR THIS STUDY

In order to obtain some indication of total activity patterns, the design for sampling activities was divided into two parts, namely, "during school hours," and "after school hours." Both parts will be described, but consideration will be given the "during school hours" design first.

The study was primarily interested in learning faculty activity during the hours when university classes are in session and when practically all official university business is conducted. For the university in question, these hours are from 8:00 A.M. to 5:00 P.M. Monday through Friday, with the exception of 12 noon to 1:00 P.M. when no classes meet; and from 8:00 A.M. to 12 noon on Saturday. This total time during the week is 44 hours, and this figure is used as a base for a week's activity throughout the study.

Deciding what number of observations to make during a 44 hour week was the next question. The usual way to do this is to determine the accuracy of result required and then compute, using the formula for standard deviation of the binomial mentioned earlier, or consult tables, to ascertain the number of observations necessary to achieve this. The higher the degree of accuracy desired, the greater the number of observations required.

This typical approach to observation limits was not used in the present study. It was clear from the list of categories adopted that it would seldom be possible to simply observe activity at the appropriate time and place it in the right category. It has already been noted that the activities are not simply physical movements that are easily recognized, but instead are actually purposes for which the activity occurs. With this in mind the number of observations was limited to the number of times a day it was thought that a staff member could be disturbed for the purpose of this study before he would become annoyed. The answer, intuitively determined, was four times a day.

It was also arbitrarily decided to carry out the study for one complete semester of 16 weeks so as to include a full cycle of academic activities. This resulted in a theoretical number of 7040 observations to be noted for the 20 teachers in the group. After losing 440 observations in order to measure observer effect (discussed later) the net theoretical total was 6600 observations.

Class periods extend for a total of 50 minutes and there are 10 minutes between classes. For purposes of sampling, therefore, the entire day was divided into 10 minute intervals. Through the use of a table of random numbers, four 10 minute periods were selected for each day (two on Saturday) during which observations were to be made. The 10 minute period was sufficient to allow the observer to make a complete round of observations and record the activity which was occurring at the instant he first saw the subject. The path of observation was varied so as to minimize the possibility of bias due to the order in which the observations were made.

Basically, the task of the observer in this portion of the study was to ascertain the actual activity in which the subject was occupied at the instant of first observation during the selected 10 minute interval. In some cases this could be done by simple observation as in cases when the subject was grading papers or talking with a visitor. In most cases, however, the observer could not be certain of the nature of activity and so it was necessary for him to ask the subject. In instances when the subject was not at his desk or could not be found at the time of the observation, it was necessary to check back with the subject later. The observation in this case was naturally dependent upon the memory of the subject. If the subject could not recall his activity at the time in question, the observation was omitted. In all, only 29 observations were lost due to failure of memory.

The second part of the sampling pattern concerned activity "after school hours." The degree to which the teachers in the subject group performed their chores during the evenings or on weekends was not known; so it was felt that there would be value in ascertaining this although to do so would not necessarily require so elaborate a sampling design.

The 16 week semester consists of 112 days including Saturdays and Sundays. It was decided to select 20 of these days at random using a table of random numbers for each subject in the study. For each selected day the subject was asked to report the total time he spent after school hours on each kind of activity having to do with university business. "After school hours" was interpreted to mean any time not during school hours, including Saturday afternoon and all day Sunday. The 20 separate days were selected at random for each subject. In other words not all subjects were questioned concerning after hours activities on the same day.

The information sought regarding after hours activity was somewhat different from that sought during school hours. Observations during school hours were instantaneous, whereas questioning concerning after hours activity depended entirely on the subject's ability to recall his total time spent on any particular activity during the

previous evening or weekend. In practically every case, however, the question was posed on the following day so that recall was not particularly difficult.

THE OBSERVER EFFECT

One of the disadvantages of the all-day study method of learning the behavior pattern of any subject is the effect the observer may have on the subject. With the observer constantly present there is temptation for the subject to modify his behavior for the benefit of the observer.

With the work sampling method, however, it is almost impossible for the subject to modify his behavior for the benefit of the observer, since he has no way of knowing when the observer will appear. However, there is the remote possibility that the subject could modify his entire behavior pattern so as always to "look good" in the eyes of the observer. For this reason an attempt was made to discover what, if any, observer effect might exist.

The group of 20 subjects was randomly divided into two groups of ten each. The study was started with group A on the first day of the semester. Group B, however, had no contact with the study until the beginning of the third week of the semester. This permitted a comparison of the two groups during the third week in order to discover any possible observer effect, particularly in regard to personal activity. It was deemed unlikely that any subjects could purposely modify their behavior for several days or more for the benefit of an observer who appears only four times a day at chance intervals.

The reasoning outlined above sounds fine in theory, but in this particular case it proved to have certain weaknesses in practice. A comparison of results of the two groups reveals some basic and consistent differences between groups A and B throughout the semester. In an attempt to discover a basis for the apparent differences an investigation was made regarding the specific individual members of the two groups. Two factors were discovered which seem to account for the aberrations noted. First, of the five persons most concerned with university research projects, four happened to be in group B. Secondly, of the seven subjects who were taking courses for credit as part of personal development, five happened to be in group B.

Prior to the study it was reasoned that observer effect would most likely occur in the category of personal activity since the other headings connote constructive effort rather than idleness. However, a comparison of the two groups in this respect also failed to show any clear-cut results. The conclusion is that the division of the entire group of 20 persons on a random basis was an unlucky one, for it happened to result in two groups so basically different in make-up that it is impossible to determine the degree of observer effect (if any) with any sort of accuracy. No doubt a much larger group of subjects is necessary in order to make this method of determining observer effect successful.

DATA COLLECTION PROBLEMS

In collecting data for a study such as this one, it is inevitable that certain problems and complicating factors are encountered. The first such complication rests in the fact that the various subheadings in the list of activities are not mutually exclusive. They were not necessarily meant to be. It is apparent that a staff member who attends a meeting off campus may also be developing himself somewhat professionally as well as possibly helping himself prepare for a class the next day. Many similar composite activities can be cited which might involve several subheadings at the same time. Although this did present an occasional conflict, each observation was noted under the heading that appeared to be the primary motivation.

Differentiating between the categories of personal development and research also presented some problems. Research, for the purposes of this study, was defined as assigned research and therefore did not include any research carried on independently by a faculty member, or research of graduate students which the faculty member supervises. The two latter types of research were classed as personal development, and student counseling, respectively. It was noted that many staff persons use the word "research" in a very generel sense; so it was necessary to give special attention to this problem of classification.

"Consulting" is another word that professors interpret variously. To some staff members, consulting described any activity they were paid for doing outside the university, regardless of its nature. To be classified as consulting, for the purpose of this study however, the outside work had to require the professional abilities of the subject. Other activities for which pay might be received were considered to be hobbies or otherwise non-professional in nature, and therefore were classified as personal activity in the study.

Some difficulty was experienced on those occasions when a staff member was technically doing more than one thing at one time. A more accurate description of this situation would be that he was *responsible* for more than one thing at one time. This is the case, for example, when a laboratory instructor grades papers while his students conduct their experiments. Although at the moment no student is asking a question, the instructor is still responsible for conducting the laboratory period. In such a case, the activity was classified as whatever he was actually doing at the moment of observation—"in class" if he happened to be working with a student, or "course follow-up" if he were grading papers. The main point was to distinguish between activity dealing with the conduct of the laboratory and any other activity.

Situations similar to this occurred when a subject was generally engaged, for example, in grading papers and perhaps had been for an hour or more. At the actual moment of observation, however, he may happen to have been discussing a basketball game with a fellow staff

member. The temptation on the part of the subject was to report that he was grading papers; however the purpose of the study was to learn how he *did* spend his time, not how he *intended* to spend his time. In such a case, therefore, the observation was recorded as personal activity.

From time to time in the earlier stages of the study staff members attempted to predict their activities by saying they were going to spend an entire day engaged in some activity such as grading papers. The implication was that the observer could just fill in his sheet for the day ahead of time and thus avoid bothering the subject. This, of course, could not be done, but the situation did require considerable tact in following up on observations as well as further education of the subject into the true nature of the study. Incidents of this nature decreased during the semester which indicated better understanding on the subject's part.

By no means should these items mentioned be considered a compilation of all the problems encountered in collecting all the observations in connection with this study. These few examples are presented to give the reader some appreciation of the problems encountered in a study of this kind as well as the manner in which they were handled.

THE STUDY IN RETROSPECT

Although this paper has concentrated on methods rather than results, a brief summary of the results is noted below for those who may be interested. On the basis of the 44 hour week as defined earlier the staff under observation divided their "during class hours" time as follows:

	Observed Percentage	*Confidence Intervals*
Teaching	41.9%	40.7 — 43.1
Research	4.0%	3.5 — 4.5
Administration	16.0%	15.1 — 16.9
Miscellaneous	20.4%	19.4 — 21.4
Personal Activity	17.7%	16.8 — 18.6
	100	

The staff also spent an appreciable amount of time each week on university business outside the basic 44 hours. The figure proved to be 10.8 hours per week for the average staff member in the department studied.

By referring to the "during class hours" results above and substracting the personal activity observations from the basic 44 hours week, we obtain a figure which represents the average amount of time the "typical" staff member devoted to university business during the basic week. This figure is 36.3 hours, which if added to the average "after class hours" figure of 10.8 yields the sum of 47.1 hours thus representing the total time spent on university business each week on the average by staff members in that department. The total figure is the only one of significance since as we pointed out earlier there is no time requirement generally as to when the staff member should do his work other than meeting his scheduled classes.

It is not possible to appraise these results since to the author's knowledge there are no comparable data available. Fundamentally, however, the study was not particularly concerned with producing information usable from a university administration point of view. All the data on individuals have been held in strictest confidence as promised to the participants. The summary data have no value to university administration since there is no way of knowing whether or not it is "typical" of faculty behavior or whether or not it might provide a basis for commendation or criticism of such behavior. In other words there is no criteria of what is "right" for a college professor to do with his time. It is not suggested that there should be.

The main objective of the study was to determine if a workable method could be devised and applied for the purpose of learning faculty behavior patterns. Conceivably, if this could be accomplished, school administration could utilize work sampling to analyze faculty activity and thereby gain some useful data for operating their departments effectively.

The author does not claim that the method devised and used in this study is the best one possible for determining engineering faculty activity patterns. Like any pioneering procedure, it is presented more as "food for thought" to others who may contemplate making studies of a similar nature. To those persons the following suggestions are also offered.

The results of this study have no practicability and may only be termed "interesting"; however, if a similar study were to be made in order to benefit the academic administrator, much more attention should be given in advance to the *use* to be made of the results. Thus in the design more discrimination in the selection of activity categories should be shown. Some of the subheadings used in this study could be effectively combined, whereas others could be expanded because they yield information of greater value. In other words, a study made in order to benefit and improve the operation of an academic department should be designed with that goal in mind rather than designed merely for the purpose of finding out what people are actually doing with their time.

The problem of the faculty member's absence from his desk at the time of the observation was solved in the course of this study by a return visit to him, and asking him to remember his activity at the moment in question. This is an admitted weakness of the study and offers another opportunity for improved design in future studies. In this case, it was considered preferable to depend upon the individual's memory rather than to include a category "not in office." The use of recall was a more serious drawback when used with staff members who performed largely administrative duties, than with those who per-

formed largely teaching duties. Teaching duties involve large blocks of time such as periods spent in grading papers or in course preparation which can be remembered with relative ease. Administrative duties tend to be more varied and shorter in length. On the other hand, the administrator is more likely to be at his desk, thereby eliminating the necessity for recall.

Recognition of the fact that teachers perform a considerable portion of their work outside the normal class or office hours should definitely be included in any future study of university faculty. In the present study this information depended almost entirely upon the memory of the subject, but in a similar study this area of design should be improved. For example, a system of direct contact by telephone at random times could conceivably provide more reliable information.

Any system of investigating faculty activity is certain to contain drawbacks as a system, but the most serious drawback to any such system is the delicate matter of interfering with academic freedom. If this disadvantage can be overcome and full cooperation and understanding secured from the staff members concerned, it is the contention of this paper that the work sampling technique is a relatively easy, inexpensive, and accurate method of discovering activity patteerns of a faculty. Knowledge of these patterns and effective use of this information can do much to improve the administration of academic departments. By increasing the effectiveness of current engineering faculties we may thereby help in alleviating the shortage of engineering faculty in general.

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A Biologist in Steel

by **OWEN GILBERT**

Operational Research and Cybernetics Department, United Steel Companies Limited, Sheffield, England

TO SUCCEED nowadays one must be a specialist, if not in one's own eyes, at least in other people's. The élite of specialists are, of course, the scientists, who in their popular image, delve in very narrow fields. In fact, however, many scientists could equally well be call "generalists." In my previous job, I was working on the formation of forest soil, a fairly restricted topic with only a small band of devotees. Yet in the course of my researches, I found myself involved with the digestive systems of earthworms, the chemistry of leather formation, the physics of clays, the climate of northern England, the statistics of small samples, and the biochemistry of proteins, to name only some of the relevant subjects. On the technical side I experimented with, among other things, the durability of plant labels, the efficacy of sulpha drugs, the toughness of rot-proof curtaining, the way to make cockroaches diet, and how to estimate radio-active carbon. Experimental scientists will recognize the theme, a theme common to much scientific research; that of following investigations where they lead and marshalling techniques, often rather scruffy techniques, to solve problems as they arise.

A COMPARISON

Biological research and Industrial Engineering, a term not greatly used in Britain, are strangely similar. Coming into Industrial Engineering from a biological research laboratory some eighteen months ago, I have been very interested to compare them. The kinship is based, I think, on the fact that both the biologist and the Industrial Engineer are trying to understand complex dynamic situations, where certainty is rare and where probability is common. Life, like industry and commerce, is not only complex, it is also contrary, and so biologists, together with Industrial Engineers and economists, lean heavily on statistics. In fact, biological research, especially genetical and agricultural research, has been a greater spur to the development of statistics than has any other branch of science. While in industry I have been particularly interested to see the ways in which assignments in Industrial Engineering are tackled. I was told during my time as a graduate student, during, as it were, my apprenticeship to research, that there are three main hurdles in effective investigation; first, the judicious definition of the problem, second, the choice of techniques to provide

relevant information, and third, the choice of techniques to analyze the information. I have not found that skill in problem-definition is a more marked trait of scientists than of Industrial Engineers. This phase of research requires in anyone an ambivalence which betokens a peculiar mental make-up; while trying to circumscribe a problem one must be open-minded to the verge of hysteria, whereas once definition has been achieved, one must be almost obsessively singleminded in solving the problem in hand.

Deciding how data are to be obtained is a phase of research which often does not loom as large in Industrial Engineering as in biological research. O.R. scientists tend to gloss over data collection and consequently often build much theory on sparse fact. Work study personnel, on the other hand are inveterate fact-grubbers but often give little thought to the best ways of obtaining their information. The experimental scientist, however, whether biologist, chemist or physicist, spends a great deal of time deciding how best to collect his data and a lot more time collecting it. In analyzing data, many work study people regard the conventional charting techniques and other time-hallowed methods as immutable, and if not God-given at least sanctified in use by the great pioneers. In contrast to such traditionalism, the other extreme is exemplified by some O.R. scientists, to whom the solution of industrial problems is of secondary interest to the development of techniques. Although very different, both the extreme work study approach and the extreme O.R. approach can be described as technique-oriented. Between the two there are other Industrial Engineers who, heretically, remain problem-oriented. These are the people who have most in common with the experimental scientists in that they follow the problems where they lead, calling in experts when occasion demands. It is these people who are already the general practitioners recently championed by W. E. Alberts as the key to the future success of Industrial Engineering (1).

BASIC DIFFERENCE

One of the basic differences between academic scientific research and Industrial Engineering, is that the scientist strives only to describe—some would say explain—what has been observed, whereas to the Industrial Engineer description is only the first stage; he must try to improve what he describes. In my move from one world to the other I have found this added factor very stimulating. However, the most noticeable difference between scientific research and Industrial Engineering is in communication. The scientist has his communication troubles; writing up his results for other scientists to read and trying to keep abreast with what other scientists are trying to tell him. But most scientists manage to earn a livelihood without ever making their endeavors comprehensible to the layman. Communication with laity is, however, essential in Industrial Engineering. On the one hand objectives have to be made clear to the work people, while on the other, both findings and potentialities should be understood by the management. This latter, communication with management, is paramount. The extent of the success in this sphere determines the Industrial Engineer's status in industry, whether he regards what he does as work study, O.R., or something else. Scientists are not so vulnerable. Their research can continue unnoticed for decades, with everyone happy despite obscurity. But for all their strong ties with scientists, Industrial Engineers cannot live that life. They must make themselves heard with effect throughout industry if they are to maintain any professional dignity.

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Incentive Wage Practice for Restricted Work

by **MAXIMO HALTY**

Fabrica Uruguaya de Neumaticos, S. A., Montevideo, Uruguay

IN THE present status of mechanization in industry, any wage incentive program should provide an adequate potential incentive for restricted work, that is for manual work restricted by the accompaniment of machine.

In such cases of restricted work, the solution to the problem of providing allowance for machine time cannot be fulfilled with pure work measurement techniques but must involve the special design of a wage incentive policy.

STRAIGHT STANDARD HOUR

The first approach in our plant was to ignore the effect of work restriction. No formal consideration was given to the presence of work restriction in the standard time development. The formula for computing the standard time is:

$$Standard\ Time = External\ Time + Machine\ Time$$

Advantages

1. The main advantage is that this procedure follows the policy of measuring elapsed time as the basis for time standard determination.
2. It is simple and straight-forward.

Disadvantages

1. This system does not provide sufficient and adequate reward due to its earnings potential limitation, because only the unrestricted portion of the cycle can reflect increased pace of work. Therefore, it does not properly motivate manual labor performance.
2. Furthermore, it does not motivate maintenance of equipment performance, due to the fact that the manual work pace index is rewarded with a lower earning index. This disadvantage is especially significant in all cases of expensive equipment.

STANDARD HOUR WITH CONSTANT MACHINE INCENTIVE ALLOWANCE

Due to the two disadvantages stated above, which were especially significant for our plant, the second approach followed was to provide constant machine incentive allowance. The time values were adjusted in such a manner as to incorporate an automatic bonus of constant percentage for restricted portions of the work cycle; that constant percentage was based upon the expected level of 125% performance. In this case:

$$Standard\ Time = External\ Time + 125\%\ Machine\ Time$$

Advantages

1. The system provides greater incentive to the worker, and this greater earnings potential motivates maintenance of both manual and equipment performance. The main reason for our using this approach was the advantage of increasing equipment and labor performance and thereby increasing productivity.

Disadvantages

1. It does not provide equitable earnings because the worker earns an incentive allowance for the machine time without actually working for it. Therefore, it does not follow the basic incentive principle of extra pay for extra work.
2. It does not take into consideration internal work time.
3. With an intentional slow down action to reach only 100%, due, for instance, to some Union decision, less production than that corresponding to 100% manual efficiency is obtained, because an earnings index of 100% efficiency corresponds to a smaller manual efficiency. This was the main reason why we developed the following new system.

STANDARD HOUR WITH VARIABLE MACHINE INCENTIVE ALLOWANCE

The basic philosophy behind this approach to solving our problem was to grant a variable machine incentive allowance, in order to make the earnings index exactly equal to the actual manual work index in any work situation.

This condition should be the goal for any incentive structure. It is accomplished by most normal incentive systems in the usual cases of unrestricted work.

If it could be established for a restricted work situation, we would reduce the problem to a basis somewhat equivalent to the case of unrestricted work.

DEFINITION OF TERMS

In order to avoid misunderstandings, the terms used are defined as follows:

E—External Time: Standard time for unrestricted work performed external to the machine time.

M—Machine Time: Constant time requirement for the restricted portion of the cycle.

I—Internal Time: Standard time for work performed during the machine time.

Id—Idle Time: Cyclical idle time when any required internal work is performed at normal pace.

S—Standard Time: Total standard time allowed for the operation.

W—Manual Work: Standard time for manual work (that is the sum of external and internal time).

Wi—Work Index: A measure of the pace or efficiency of manual work.

Ei—Earnings Index: The index used for determining the worker earnings.

MATHEMATICAL COMPUTATIONS

The work index by definition is the standard manual work minutes produced, divided by the actual work minutes used for performing the task. The standard manual work minutes produced are:

$$P(E + I) = P \times W$$

where we call P the number of productive cycles performed and W the standard manual work time per cycle.

The actual work minutes used for performing the produced standard work minutes are:

$$H - P\left(M - \frac{I}{Wi}\right)$$

where we call H the total number of time card or elapsed minutes utilized for performing the operation.

Then, as

$$M - \frac{I}{Wi}$$

is the idle time when the internal work is performed at actual pace,

$$P\left(M - \frac{I}{Wi}\right)$$

represents total actual idle time.

Therefore,

$$H - P\left(M - \frac{I}{Wi}\right)$$

represents actual work minutes.

Consequently, the work index is:

$$Wi = \frac{P(E + I)}{H - P\left(M - \frac{I}{Wi}\right)} \qquad \text{Eq. 1.}$$

Simplifying the expression:

$$Wi = \frac{P(E + I) \times Wi}{H \times Wi - P(M \times Wi - I)}$$

$$1 = \frac{P(E + I)}{Wi(H - P \times M) + P \times I}$$

$$Wi(H - P \times M) = P(E + I) - P \times I$$

$$Wi = \frac{P \times E}{H - P \times M} \qquad \text{Eq. 2.}$$

Wi is independent of internal time and could obviously then be used for any case of $I = 0$ or $I \neq 0$.

Furthermore, calling f the variable machine time incentive allowance, the standard time in minutes per cycle is:

$$S = E + fM$$

and consequently the earnings index will be the standard value per cycle, times the number of cycles produced and divided by the total time card minutes.

$$Ei = \frac{P \times S}{H} = \frac{P(E + fM)}{H} \qquad \text{Eq. 3.}$$

We want to determine a variable machine incentive allowance f that makes in any situation $Ei = Wi$.

Therefore:

$$Wi = \frac{P \times E}{H - P \times M} = \frac{P(E + f \times M)}{H} = Ei$$

$$E \times H - P \times E \times M + fMH - PfM^2 = E \times H$$

$$fM(H - PM) = P \times E \times M$$

$$= \frac{PE}{H - PM} \qquad \text{Eq. 4.}$$

Observing Eq. 2. and Eq. 4. we see that $f = Wi$.

Then, the variable machine incentive allowance which makes $Ei = Wi$ is exactly equal to the manual work index, this statement being quite predictable. Thus we are going to pay a variable machine incentive allowance exactly equal to the actual manual work efficiency in each work situation.

The pay will then be the machine time multiplied by a certain amount which is exactly equal to the pace index which the worker actually works during the unrestricted part of the cycle, the manual work index Wi.

The standard value to be used for determining the bonus according to this incentive structure is:

$$S = E + fM = E + WiM \qquad \text{Eq. 5.}$$

$$\text{Replacing } Wi = \frac{P \times E}{H - P \times M} \qquad \text{Eq. 6.}$$

$$S = E\left(1 + \frac{P \times M}{H - P \times M}\right) \qquad \text{Eq. 7.}$$

EARNINGS COMPUTATION

As is seen in Eq. 5. we have a daily variable standard time for the operation which can be figured from the daily manual work index. This index can be easily figured (Eq. 6.) when the daily output P and the time card time utilized in the operation H are known.

Finally, we can figure the standard time from the two daily data P and H. (See Eq. 7.) The earnings computation is much simpler, since our starting point was to make $Ei = Wi$. We now have for computing the daily bonus:

$$Ei = \frac{P \times E}{H - P \times M} \qquad \text{Eq. 8.}$$

Replacing daily P and H we can figure by this simple mathematical equation the daily earnings index and

therefore the daily bonus. For computing Ei we may also have a graphic way. From Eq. 8, we may write:

$$Ei = \frac{E}{\frac{H}{P} - M} \qquad \text{Eq. 9.}$$

Then we may draw Ei as a function of the daily variable H/P, as indicated by Figure 1. This graph can be drawn during the standard computation, attaching also the standard time as a function of H/P:

$$S = E\left(1 + \frac{M}{\frac{H}{P} - M}\right).$$

By means of the graph of Ei as a function of H/P, it is very simple for the time keeping clerk to figure the daily earnings index and daily bonus by computing the simple ratio H/P using Figure 1.

FORMULA GENERALIZATION

When an operator works the same day in two or more restricted work situations it can be easily demonstrated that:

$$Ei = Wi = f = \sum_{j=1}^{j=n} \frac{P_j E_j}{H - \sum_{j=1}^{j=n} P_j M_j}.$$

INCENTIVE STRUCTURE DISCUSSION

Advantages

1. It follows the basic principle of any normal incentive plan to make the earnings index equal to the manual work index.

2. The system provides adequate and equitable earnings; it appears completely equitable and fair to pay the machine time, which is the time the worker has no control of, with the efficiency rate the worker actually works in the manual part of the cycle.

3. In this way the bonus is completely proportional to the worker effort. We are obviously paying the external work according to the pace rate, and as we are paying in this system the machine time to that rate, then the whole cycle time is paid according to the worker effort.

4. Therefore, we are reducing the problem of restricted work to an unrestricted work situation. The bonus is completely proportional to the worker pace.

5. It does strongly motivate manual labor performance because labor knows that the whole cycle time will be paid with the same rate of their manual work efficiency; consequently they are very interested in decreasing the actual manual work time.

6. It does motivate equipment performance because as is indicated in the preceding paragraph, the workers tend to decrease the external time, and therefore an increase in equipment productivity occurs.

7. A very significant advantage, related to our problem of intentional slow down action is that the earnings index reflects proportionally the manual slow down. Therefore, the problem of the system of constant incentive allowance of obtaining less production than that corresponding to 100% manual efficiency, when the slow down action tends to reach only 100% earnings index, is avoided. When the worker tends to reach only 100% earnings index, his manual efficiency is 100% and consequently the production obtained is corresponding.

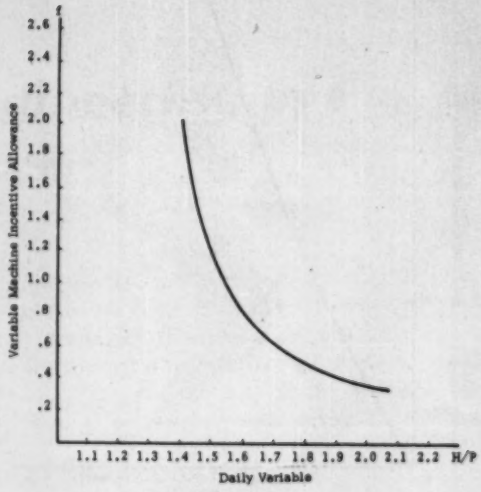

FIG. 1. Plastic Wire 2 mm Extruder No. 4.

Disadvantages

1. The earnings computations are not too simple, but this disadvantage is avoided by the use of charts. The utilization of these charts although simplifying the earnings computations, make somewhat more difficult the mathematical computations of the standard development. This last difficulty is not important.

2. Observe that the earnings index is proportional to the manual worker pace, it is not then directly proportional to production; the earnings index as a function of production has the hyperbolic shape indicated in the graphs.

It is clearly seen that for little variation in output great differences in the standard value and therefore in the earnings index are obtained. This is obvious because due to the special characteristics of restricted work, a small variation in output requires a great increase in manual pace, the amount of this difference depending on the degree of restriction.

Due to this aspect of high sensitiveness to output variations, adequate provision should be taken for controlling production counts. The same precautions should be taken for controlling the working time, due to the fact that a little variation in working hours represents great variation in earnings index.

Briefly, it is absolutely necessary to have perfect control of the production count as well as of the working time before using this system.

APPLICATIONS

This new system structure has been successfully installed in our wires and cables department. Although it is not possible to have definite results, due to the limited time elapsed since it has been in use, the first results indicate a 10% increase in production and equipment utilization.

The same basic principle of making the earnings index equal to the work index has been used in a somewhat different way in a line of our tire curing department. It is a line of fifteen people working on a roller conveyor where the molds from seven different vulcanizing ovens are discharged of their cured tires and charged with green ones.

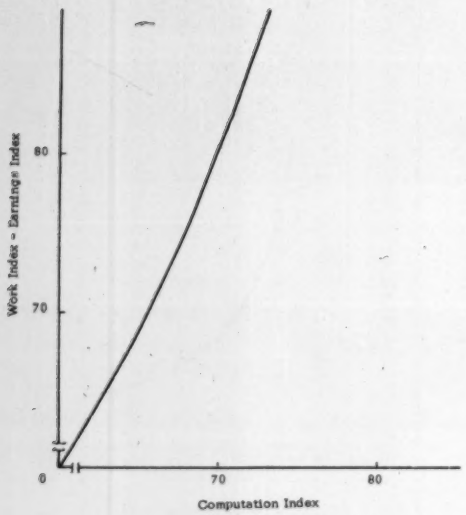

FIG. 2.

The graphical method was used for determination of machine interference and labor idle time. The standard time equals the manual work time plus the idle time, where the idle time is determined from the graphs at normal pace.

For each daily output using the preceding standard time value, we have a corresponding efficiency index, which we called the computation index. If we use this computation index for earnings computations, that is as earnings index, we are applying the first bonus system described in which the idle time is paid at normal pace.

Willing to apply the general philosophy of making the earnings index equal to the work index, we made four graphs with manual work at a 110%, 125%, 140% and 160% pace rate. We figured the outputs related to these work indexes. Afterwards the corresponding computations indexes were computed, and a graph indicating the relationship between the computation index and the work index could then be drawn.

Making the work index equal to the earnings index, the corresponding earnings are shown for each computation index. (See Figure 2.) If we make the computation index equal to the earnings index we pay the idle time at normal efficiency (first bonus system).

If we use the graph which indicates the relationship between the computation index and the work index, and we make the last one equal to the earnings index, we are paying the idle time at the actual work efficiency (third bonus system).

This example is an illustration of the same basic principle of work index equals earnings index, but using a graphical way instead of formulas.

CONCLUSION

This new wage incentive structure for restricted work which borders on the same basic principle of granting a bonus directly proportional to the worker pace as in any usual unrestricted work situation, seems to solve theoretically one of the most important problems of wage incentives programs—work restriction.

For any practical applications a careful study should be carried on before using it in each special case to be sure that the production count as well as the working time controls are extremely accurate.

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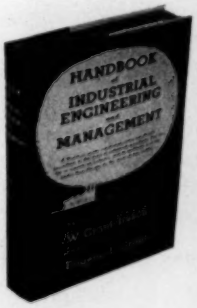

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Notes on Industrial Engineering in Europe

by **T. E. FOUGNER**

Production Engineer, National Carbon, Division of Union Carbide Corporation

EUROPE consists of about 19 countries west of the Iron Curtain and about seven Russian satellites east of it. In addition to this, there are approximately five very small states. The countries in Western Europe vary widely in such things as size, form of government, standard of living, and language. The size varies from Monaco's 370 acres to France's 213,000 square miles, the population from Monaco's 3000 citizens to Western Germany's 50 million.

The governments, with a few exceptions, are all elected by free ballot. Their policies range from Western Germany's free enterprise system to the Scandinavian countries' socialism, and their form of government from Switzerland's almost pure democracy to Spain's dictatorship. The standard of living varies from one country to another, but in all European countries it is considerably lower than in the United States. As an example, a young married engineer in Norway would have to spend almost 60% of his income on groceries, house rent and taxes. In this country, I have found that the same expenditures require about 40% of the income.

There is a customs barrier between the majority of the European countries which means that duty must be paid when goods are moved across a border. In a few cases, such as Switzerland, duty is imposed mainly to provide the government with revenue. In the majority of the cases, however, the customs barriers are tailored to produce revenue and to provide protection for local industry.

The trade between the different European countries has also been hampered by the lack of foreign currency, although this situation has been vastly improved since the years just after World War II. All of this tends to break the large European market up into small sections and make the formation of industrial giants and their mass-production of consumer goods difficult. Even products like automobiles, which are made by a few large corporations in America, are built by several independent companies in each of the most heavily industrialized European countries.

The recently formed European Common Market may in time bring a change in this situation. The E. C. M. consists, for the time being, of Western Germany, Belgium, Holland, Luxembourg, France and Italy, totaling 166 million people. These nations have agreed to remove all trade restrictions between their countries over a twelve to fifteen year period. It is expected that the common market will also cover the remaining European nations in one form or another. However, Rome was not built in one day. The obstacles for a free trade between the European nations will not be removed overnight. In the meantime, the majority of the European manufacturers must be satisfied with serving a limited market.

SHORT PRODUCTION RUNS

There are a number of factors, aside from limited markets, which tend to prevent American style mass-production in favor of short production runs. One factor is that the number of manufacturers in the same market is too high, in some cases leaving too small a share of the market for each manufacturer to operate efficiently.

If competition were allowed to run its full course, the number of manufacturers would be reduced. However, there are a number of restrictions on free competition. One is the customs barriers, behind which small companies with inefficient production can blossom, relatively unhampered by larger and more streamlined companies in the surrounding countries. Another restriction to free competition is that, in some countries, it is not illegal for the manufacturers of the same product to consult and agree on common prices. This is done to a large extent, thereby eliminating price competition from many products. The customers will buy from the manufacturer with the most attractive service and/or sales approach, but not necessarily from the one with the most efficient production, thereby permitting the weakest manufacturer to stay in business much longer than he otherwise would have been able to do. With this high number of manufacturers in each field, the production runs become short. It is therefore important that the machinery used is easily set up for different sizes and different products.

My experience in Norway was with a tin can manufacturer, and I recall that we would pore dreamily over a pile of catalogs describing American tin can making machinery. We would read about automatic punch presses that could spit out 40,000 lids a shift, and we knew that our manually operated ones were incapable of more than 10,000. But we also knew that we could change the die in our punch-presses in about an hour, and that those American speedsters would require more than one shift to change over to a new size. With the size of our orders, it was hard to justify the purchase of a high speed press.

Universal machines that can be used on many sizes and on different jobs find a wider application on short production runs than specialized machines, even if the latter have a higher production speed. It is clear that a high speed does not help very much if the equipment can be used but a short time of the year. As an example, in our tin can plant we had an automatic can making line and a number of lines where each machine was manually operated. Even though the automatic line could be used for three or four sizes, it was required less than half the time. The manually operated lines, which could be set for almost any size we made, were running year round.

STANDARDIZATION

It is obvious that under these conditions standardization, or more specifically a limitation of the number of types and styles made, is becoming very important. Only when the number of types and styles are limited can the costs for design and for jigs be spread over as large a number of pieces as possible. By manufacturing only one or a few types, time otherwise lost in changeovers from one type to another is saved, and special equipment which otherwise could not have been jutified can be put to economical use.

Outstanding examples of this standardization can be seen in Europe today. For example, the telephones built in Norway are designed for use both on a wall or on a desk, thereby eliminating the need for two separate types. Another example is a line or air-compressors, put out by a Swiss manufacturer, utilizing one basic crankshaft and crank case, on which from one to three identical cylinders can be mounted in a V-fashion. The crank case is designed so that two can be used with a common crank shaft, thus providing from one to six cylinders, depending on the desired output. For any combination the majority of the parts are the same, which gives the manufacturer an advantage in production which is reflected in his prices. The problem of spare parts is also vastly simplified.

Even though a lot has been done in the way of limiting the number of variances, there still remains much work. For example, tin cans are made for the same market with diameters of 3.98 and 3.91 inches. The height of both cans is the same. The reason for this apparently unnecessary difference is that some canners have their equipment set up for one size, some for the other. Because the prices are fixed, no single can manufacturer is able to standardize on one of these two sizes and thereby try to get a lower price for the standardized dimension. A standardization, and subsequent change in the prices, would require acceptance of the change by all can makers.

WAGES

Frequently, when the competition from Europe becomes intense for American manufacturers, it is argued that low European wages afford cheap prices. It takes more than low wages to make a product that will sell in a competitive market, but certainly wages are considerably lower in Europe than in the United States. Regional variances exist as they do in this country, but wages generally are between 60 and 80 cents per hour. Consequently, equipment that would be a good investment in this country does not necessarily pay in Europe. For example, in our tin can plant the finished cans were boxed and the boxes stacked on the floor. From the floor, the boxes were stacked on carts and pulled by a worker from the manufacturing area to the storage area. The worker would then take the boxes from the cart and stack them as high as possible, frequently with the help of a second man standing on a ladder. In the United States an Industrial Engineer would easily figure a substantial saving by the use of a fork truck and pallets for this job. However, with the wages these cart-pullers received we were unable to justify any type of mechanization of this work beyond minor improvements to the carts.

Frequently the equipment needed must be imported from some other country, and might therefore be subject to various duties which do not make it easier to justify its purchase. It is, however, customary to allow the equipment a longer time to pay for itself than is the practice in this country. For instance it is considered acceptable to buy a $5000.00 piece of equipment that will require four to five years for the investment to be realized; on more expensive equipment the time can be even longer.

INCENTIVE PLANS

Incentive plans have found wide application in Europe. In Norway a vast majority of all operations that lend themselves to these plans are on incentive. The incentive plans are not only used in the manufacturing industries, but also in construction, where such craftsmen as bricklayers and electricians, as well as the unskilled or semi-skilled laborers, expect to get paid according to what they produce. Because of the difficulties that easily arise where some employees in a plant are on incentive and others not, there is a tendency to try to cover jobs by incentive which were not previously considered suitable for this, such as storekeepers and janitors.

The type of incentive plan most frequently used is a straight one-for-one type, where earnings are directly proportional to production, and the base rate is normally guaranteed. I have, however, seen systems where the guaranteed minimum was less than the base pay, and the other extreme, where a provision in union contracts guaranteed 105% of base rate.

The question of a guaranteed minimum is not very important, since rates so set that normal effort results in earnings of 130-140% of base pay are common. The ones benefiting mostly from the guaranteed minimum are therefore employees training on new jobs. The question of a ceiling on earnings is actually considerably more

important. In some cases the ceiling is put on by the company, in other cases by the employees through group discipline. The company's reasons for putting on the ceiling is to prevent excessive earnings due to incorrect rates. In some cases one finds that the company will use a certain percentage of the earnings which are above the ceiling, and therefore not paid, for some recreational purpose for the employees.

In the company I worked for in Norway, all incentive rates had to be signed by management and union to become effective. The union members in the plant had elected a man as a time study steward; it was his job to go through the time studies and the calculations necessary to set the rate, and then to recommend that the union accept or reject the rate, or to point out errors if any. In order to qualify for this job, the man was trained in time study and rate-setting techniques on company time and expense. This arrangement is quite customary in Norway.

In our case the time study steward had a very difficult job. When the question was whether or not to accept a certain rate, many of the union members would start by determining the desired earnings and then would calculate the necessary rate. Afterwards they would try to get this rate through by using every possible argument, reasonable as well as unreasonable. The time study steward was then expected to advocate these arguments. Because he had seen all studies and calculations, he knew that the rates were set as accurately as possible and it was therefore difficult for him to support wild claims. This subjected him to occasional harassment by fellow union members.

There is a creeping inflation in most European countries, and if the standard of living is to be kept constant the earnings will therefore have to increase. If management is unwilling to give any pay increases, employee pressure is on the time study department, since earnings are the product of base pay and time per piece. The time study department may have good Industrial Engineers, but not necessarily good negotiators. Therefore the rates are frequently becoming more and more out of line. At the same time, the Industrial Engineers in the time study department become increasingly disgusted with their work as they see their own carefully determined rates considered by the union as nothing but a proposal, subject to counter-proposals and negotiations.

Some companies have abandoned the incentive plans and returned to straight day work pay in an effort to get away from all these difficulties, basing pay on carefully made job evaluations. A shipyard in Norway, which recently changed over from incentive pay to day work, broke its jobs down into eight different pay groups depending on the type, skill, and experience required. Within each group they made three sub-groups. The employees were placed in the sub-group according to ability and productivity. This change was not only supported by the unions, but a union representative was quoted as saying that he would like to see similar plans put in all over the industry. A large electro-chemical company in Norway which installed such a plan a couple of years ago had difficulties with the unions before it got the plan working indicating the unions have changed their opinion on job evaluation plans.

The stopwatch is still the most commonly used tool in time study work, although predetermined times are gaining greater acceptance. Of all the predetermined time systems currently on the market in this country, Methods Time Measurement is the only one I have seen used in Europe. This system apparently established a foothold in Sweden, and from there spread to countries like Norway and Switzerland. The first courses in M.T.M. were held in Switzerland in 1953, and in Norway about the same time, and the number of people trained in this system is therefore still relatively limited. A drawback with M.T.M. is that it is not as easy for an average worker to understand as a time study. There are still certain unions which flatly refuse to accept any piece rate set by M.T.M. because they cannot check the rates as they can with time studies. Unions argue that whereas the time for the individual elements might be correct over in the United States where they were determined, they do not necessarily apply to their plant.

PRODUCTIVITY

The productivity in European industry is, generally speaking, not on a par with that of industry in the United States, but considerable improvements are being made. In this field there has been much cooperation between the different European nations. A European Productivity Agency has been formed on initiative from the United States, and it has helped with money and know-how through different foreign aid programs, such as the Marshall Plan and the Technical Aid Program. The work of raising productivity has thus become a matter of international cooperation and a field for extensive influence and consultation between the European countries. A number of programs of interest to more than one country has been organized. In this way it has been possible to make rapid progress in a field where little or no previous experience existed and where progress was a matter of trial and error.

The work of raising the productivity in the individual countries has been taken over by national agencies more and more in the last few years. Productivity has become less dependent on ready-made programs from American consultants and the European Productivity Agency. It has, on the other hand, become easier to call in specialists to set up national programs. In its first four years of existence the Norwegian Productivity Institute has worked on about 250 projects, out of which 22 were American Technical Aid Projects, and the rest equally divided between E. P. A. and national projects. The

Norwegian Productivity Institute is almost completely financed through American foreign aid programs.

The experience gained through demonstration projects, conducted to show what can be done to increase the productivity within a branch of the industry by careful and extensive analysis of one or a few representative companies, has afterwards been published in order to let the whole industry benefit from these projects. The first projects were done with the help of American consultants; later on Norwegian Industrial Engineering consultants took over.

One of the first projects received wide public acclaim because the results were so startling. Whereas many knew that production could be increased through better machinery, there were not many that were aware of how much could be done by improving methods. The first project was in two shirt companies, both considered representative of the shirt industry. Before the project was started, the companies made 10-15 types of shirts which retailed for $6-$7. The work week was 48 hours, as in the majority of European industry. After the project was finished, the types of shirts manufactured were cut down to three or four, the retail price for a cotton shirt lowered to about $4.00 and the work week cut to 40 hours without any reduction in pay. The companies' profits also increased. This certainly was startling, not only to the other shirt manufacturers, but to the industry as a whole and to the general public. Later on, more of these demonstration projects were carried out, one in shoe manufacturing, one in textile mills, where, as an example, an old accepted standard has been raised from twelve looms per weaver to twenty-two. In a furniture plant production per man was raised 50% by rearranging the machinery and by basing the production on standard parts and thereby simplifying it. It was not necessary to invest any money in new machinery to obtain this sizable increase in productivity.

The work with the demonstration projects is continuing. A Norwegian paper recently told about a company which had completed the construction of a new plant for wooden radio and T.V. cabinets. The plant was partly financed with help from the N. P. I. on the condition that the plant be open for everybody from the furniture industry who might want to share in the experiences gained. N. P. I. has recently finished an extensive lost-time study in a number of auto repair shops in an attempt to raise the productivity in this field. The study showed that only 50-60% of the mechanic's time was spent with productive work, with lost time running 40-50%. The newspapers told about the result of the study, and many people, unfamiliar with the expression "lost time," believed that it had been scientifically determined that the mechanics spent half their time drinking coffee, discussing the outlook for next week's football game, and the like. This resulted in a furious outcry from car owners who believed their repair bills to be too high, and there are many car owners like that even in Norway. The Institute had to rush to press an explanation of the technical term "lost time" to calm tempers.

The demonstration projects have not only increased the productivity in the specific industries where they have been accomplished but they have also helped break down the unnecessary walls of secrecy with have surrounded too many plants. In addition N. P. I. has financed some development programs in the Industrial Engineering field which may result in increased productivity. A number of exhibitions have been held. One, for instance, was set up by the European Productivity Agency on automation and mechanization and it visited several Norwegian cities not long ago. This exhibition shows how mechanization and automation can be accomplished through simple means.

A very important part of the work of raising productivity is to inform the general public, to help them understand that the purpose of the work is to raise the man-in-the-street's standard of living and secure his job. In an under-developed country, this part of the work may be even more important than the actual teaching of better techniques. I do not think it is correct to classify Europe as an under-developed area, but passing information is still a very important part of the work. As an example of what is being done in this field, Norwegian newspapers in 1957 had 1700 articles concerning efforts to raise productivity. If all of these articles had been one column wide, their total length would have been close to 20,000 feet.

A materials handling agency has developed standard sizes for pallets. A standardized pallet is perhaps more important in the smaller countries in Europe than it is here where a high percentage of all shipments are in carload lots. Loading railroad cars or trucks with palletized goods from several manufacturers is appreciably easier if all pallets are of one size, and that size fits the standard truck or car.

The Swiss Federal Railways have had a pallet pool in operation for six or eight years, it having been started at the suggestion of the Industrial Engineering Department of the Swiss Federal Institute of Technology. The pallet used is a wooden four-way pallet 32 × 48 inches. A member of the pool determines whether or not he should make his own pallets according to the railroads' specifications or buy them from the railroad. When making palletized shipments, the railroad returns at once a number of pallets equivalent to those in the shipment. When the shipment arrives at its destination, the receiver must either empty the pallets and return them to the railroad at once, or provide a number equivalent to those used in the shipment. All pallets are supposed to be in good condition when they change hands. Repairs and replacements are therefore done by whoever has the pallet when damaged. The railroad does not make any freight charge on the pallets in a palletized shipment. The importance of this system can only be understood if one realizes the large number of less-than-carload shipments and the great

number of transfers between car and truck required in a country where there are many small plants without railroad connections.

PALLETIZATION OF CARGO HANDLING

As an example of a type of problem frequently encountered in Europe and its final solution, there is a small steamship line which operates along the west coast of Norway where farm land is scarce and the population correspondingly sparse. The coast line is broken up by a large number of fjords with steep shores where the construction of roads is difficult and expensive if possible at all.

The region is almost inaccessible except by ship; thus ships represent to the towns and villages in this area what the railroad and the trucks are to most of this country. Because shipping is the only means of transportation, it is clear that the most diversified cargo may be expected in a single shipment and that the over-all efficiency depends on the speed of cargo handling not only at the home port but at all ports at which the vessels call. Facilities vary from a well equipped port with shore cranes to a rough wooden pier, just capable of taking the trucks delivering the cargo to the fjord.

The size of each shipment is small, their number is high and no two shipments are alike. The ships used are small, with cargo turnovers as often as six times a week. The costs for cargo handling are therefore a high percentage of the operating expenses.

Pallets and mechanical handling have now brought a solution to this complex materials-handling problem. Before the ship arrives, cargo for different posts is stacked on separate pallets, permitting each pallet load to go unbroken from shipping to receiving port. Due to the small size of each shipment, it is normally necessary to stack more than one type of cargo on the same pallet, securing the load with a net or some similar means, which precludes the stacking of pallets. The newer ships are therefore built with a between-decks height equal to the height of a loaded pallet, which is about six feet. The pallets are moved to shipside with fork trucks in the larger ports, or hand operated jack trucks in the smaller ports, and lifted on board with shipboard cranes. Once aboard, the pallets are moved around by small battery-operated fork trucks.

Some space is lost due to the palletizing, but this loss is more than compensated by the savings in handling time. Under the old system, a gang of 8 to 9 men could unload 8 to 10 tons per hour; today the same crew handles 40 tons per hour. This means that a ship today can be unloaded and reloaded in 12 hours, in contrast to 48 hours required before the handling was mechanized. The company is therefore able to provide better service with fewer ships.

The pallets used deserve some mention. They measure about 3×5 feet, weigh about 80 pounds, are built of steel pipe and are designed so that the empty pallets can be stacked into each other. A stack of 25 pallets takes up no more space than five pallets of normal design. The pallets have found a wide use in Norway, and the patent holder is developing an export market.

EDUCATION

Practicing Industrial Engineers in Europe today can be divided into two groups, engineers and technicians. Engineers are four-year college graduates who have had a total of twelve years of primary and high school, whereas technicians are graduates of a two or three-year course with ten years of primary and high school. The engineers have eight to twelve months industrial shop practice before they graduate, but technicians have at least two years shop practice or frequently a four-year apprenticeship. The purpose of this practice is to provide both a better understanding of the subjects taught in college, and to help them understand the average worker's way of thinking. The latter may not be as necessary in this country as it is in Europe, where the difference between the classes is much more distinct.

In the plants, one normally finds two technicians for every engineer, with the technicians usually performing routine jobs; consequently the engineer's possibilities for advancement are somewhat larger than the technician's. This in no way implies that technicians are excluded from the higher positions, as at least one of Switzerland's largest companies has a former technician as a vice president. With regard to the education of engineers, Industrial Engineering is not considered a branch of engineering in the same manner as civil or mechanical, and to my knowledge their are no universities or other institutions on that level in Europe that graduate Industrial Engineers as such. The Industrial Engineer most frequently graduates as a Mechanical Engineer, even though he has spent most of his last year and a half taking Industrial Engineering subjects. For his first $2\frac{1}{2}$ years, his education consists of the basic subjects such as mathematics, physics, mechanical drawing, etc. In the last year and a half the student selects one of eight or ten packaged programs offered. Each program consists of a number of different, but related, subjects. For an example, the water turbine program includes design of water turbines, exercises in the hydraulic laboratory, lectures on water metering and regulation of a water turbine. The advantage of setting the subjects up in packages is that the young student will not normally know what subjects he will need and is therefore likely to choose what he thinks interesting, only to discover too late that he missed something important.

The Industrial Engineering Package contains one series of lectures which are given over the course of a year. This series covers the whole range of Industrial Engineering subjects from production planning and time study to plant layout and quality control. In addition to the lectures, a series of exercises is given on some of the subjects covered. These are somewhat extensive and require con-

siderable effort from the student. In addition the package contains lectures and exercises in accounting and production techniques, the latter, incidentally, being introduced in the first year, is compulsory for all Mechanical Engineers, but is considered in greater detail for Industrial Engineering majors.

In the last three months the student is sent out into a plant which has a definite problem to be solved. In my case, the assignment was in a plant manufacturing textile machines. Their problem was the bulky system of forms used to issue materials from stores, assign jobs to workers, and to route material through departments, etc. At the end of the three months, the student is expected to submit a report, stating the present situation and his detailed proposals to improve it. Considerable help is given by the Industrial Engineering professor and his assistants, so that the company concerned actually receives consulting service in return for assisting a student to gain practical experience.

Graduation examinations cover ten to fifteen subjects, plus the solution of a large problem which requires about eight weeks. In the case of the Industrial Engineers, the problems are again found in actual plants and are similar in scope but different in nature to those assigned previously; also the time allowed is considerably shorter.

The education I have described is that in Switzerland, and it is closely aligned to that of other German speaking countries, the Scandinavian countries, and Holland. In England, the education is mainly limited to graduate courses at a few universities; however the Industrial Engineering curriculum in that country is expanding.

In my opinion European Industrial Engineering education is lacking in the newer techniques based on mathematics. Statistics are not compulsory for any engineers, including the Industrial Engineer. Lectures are offered on statistics, but as the majority of the students are well occupied with the compulsory subjects, they will omit as many of the elective courses as possible. As a result, the average graduate knows little about statistics, and less about the techniques which are based on statistics. However, a brief introduction to statistical quality control is given, and such techniques as ratio-delay are described only to the degree necessary for a student to use them.

I assume, however, that a change in this picture will be seen before too long. Judging from current articles in European magazines, there is a strong interest in such areas as operations research, statistical quality control, and the use of statistics in production control. Some European companies are now using these techniques, but from my experience the majority of the plants are relying more on the familiar scientific management techniques.

CONCLUSION

Although Roman Civil Engineers were at work long before anybody had even thought of discovering this country, and James Watt's steam machine gave birth to Mechanical Engineering in Europe (which can therefore claim to be the birth place of these branches of engineering), I don't think there can be much doubt that Industrial Engineering was born of the large American market and the mass production that followed.

Industrial Engineering's standing in Europe depends on how fast American ideas and techniques can be brought over. Because Eruopean industry is composed of smaller units than are found here, the techniques might need some adaptation before they can be used there. Also, Europeans are sometimes slow to realize the fact that techniques developed in a large American corporation are not necessarily unsuitable for use in a smaller European company.

Because the idea that "what was good enough for my father, is good enough for me," is rapidly on its way out, I believe that Europe can look forward to an increasing import of new American techniques and ideas in the Industrial Engineering field. How long before the import of ideas is turned into an exchange of ideas is difficult to foresee, but that date may not be too far in the future, for Industrial Engineering is a fast growing, if not the fastest growing field, of engineering in Europe today.

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The Effect of Hypergeometric Probability Distribution on the Design of Sampling Plans for Small Lot Sizes

by A. E. ROKHSAR

Graduate Student of Industrial Engineering, Lehigh University

and G. E. KANE

Assistant Professor of Industrial Engineering, Lehigh University

IT IS a common practice in industry to evaluate the quality of a product by inspecting a sample from the lot of the product. The reason is rather obvious. Acceptance tests requiring destruction of the item tested are necessarily done by sampling. The cost of 100% inspection may be prohibitive or the effect of inspection fatigue involved in 100% inspection may be extreme. A good sampling inspection plan may actually give better assurance of quality than 100% inspection (2).

Development of sampling plans requires the use of the mathematics of probability since it involves laws of chances. In 1923 the engineers in the Western Electric Company first applied the theory of probability for a quantitative approach to sampling problems. The first set of sampling inspection tables for shop use were prepared in 1926 in a cooperative program between the Bell Telephone Laboratories and the Western Electric Company (1). Since then many different sampling plans have been developed; the plans differ on the emphasis associated with consumer's and/or producer's risk.

METHODS OF PROBABILITY CALCULATIONS

1. *The Poisson Probability Law.* All existing sampling plans (such as MIL-STD 105A, Philips Standard Sampling System and Dodge-Romig Tables) are based on the Poisson Probability law. This law mathematically may be expressed as follows:

$$P(d) = \sum_{c=0}^{c=d} \frac{(np)^c}{c!} e^{-np} \quad \text{where}$$

$P\ (d)$ = Probability of having d or less defectives in the sample.
c = Number of defects in the sample.
n = Sample size.
$p = D/N$
$e = 2.71828+$
D = Average number of defects in the lot
N = Lot size

This law assumes that the probability of drawing a defective article remains constant from draw to draw. This assumption is not valid in situations involving small lot sizes, because each draw changes the proportion of good and bad articles in the lot. This fact is known as "Partial Exhaustion."

2. *The Hypergeometric Probability Distribution.* The hypergeometric probability distribution takes the partial exhaustion into consideration. It may be expressed mathematically as follows:

$$P(d) = \sum_{c=0}^{c=d} \frac{\binom{D}{C}\binom{N-D}{n-c}}{\binom{N}{n}}.$$

The definition of each symbol here and in the Poisson law are the same.

Thus, the question might logically be asked at this point, "What is the effect of using sampling plans based on the Poisson distribution when situations involving partial exhaustion are encountered?" It is with this thought in mind that tables of probability based on the hypergeometric probability distribution were developed (3).

METHOD OF DEVELOPMENT AND EXTENT OF TABLES

The hypergeometric tables developed were calculated by an LGP-30 digital computer. Due to programming difficulties and rounding errors, the values of cumulative hypergeometric, though calculated correct to the nearest 0.0001, may be off by -0.0002. Therefore the cumulative probabilities are sometimes more than 1.0000 by 0.0001 or 0.0002.

The extent of hypergeometric distribution tables developed is as shown on following page.

It was discovered that the publication of tables for values of N ranging from 1 to 50 were undertaken by another source; thus the range of values for N in this

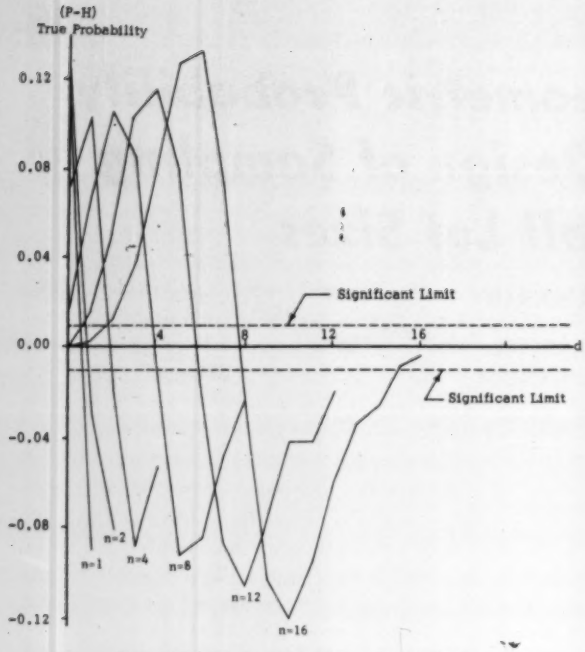

FIG. 1. $(P\text{-}H)$ vs. d for $N = 50$, $D = 25$.

study were limited to those shown, 50 to 100. This study also set the increment values of N at 50, 55, 60, . . . , 100, with the thought that the chief interest of the engineer in this endeavor was to examine the differences between Poisson and hypergeometric distributions at various lot sizes. This purpose could be served just as well as in units of one.

1.

N	n
50 & 55	
60 & 65	
70 & 75	
80, 85, 90, 95, & 100	1, 2, 4, 8, 12, 16, 20, 24 & 28

2. $D = 1(1)\ N/2$

3. $d = 0(1)\ D$ or $d\ -0(1)n$ (the smaller of n or D).

RESULTS

The arbitrary decision was made that if the absolute value of the differences between the cumulative terms of Poisson and hypergeometric, called $(P\text{-}H)$, is larger than 0.010 the difference is significant. A typical $(P\text{-}H)$ vs. d chart is shown in Figure 1. Here N and D are constant and n has six different values. For clarity -0.010 and $+0.010$ significant limits are shown as dotted lines. It can be seen that there are very few values within the two significant limits. As a general rule $(P\text{-}H)$ is insignificant when d is equal to zero, one and $n/2$.

It can be noted from Figure 1 that the effect of partial exhaustion is maximum in a positive direction with the lower defective rates, where the reverse is true when the defectives per lot are high.

TABLE 1

Comparing Values of Probabilities of Acceptance for Known Sampling Plans Calculated by Poisson and by Hypergeometric

Sampling plan	N	D	n	c	Pa* Poisson	Pa* Hypergeometric	$(P\text{-}H)$
1. MIL-STD-105A**	50	5	5	1	0.910	0.929	−0.019
2. MIL-STD-105A	100	10	7	1	0.844	0.856	−0.012
3. Philips	50	5	7	0	0.497	0.454	0.043
4. Philips	100	10	7	0	0.497	0.467	0.030
5. Dodge & Romig Single Sampling (10% LTPD)	50	2	17	0	0.507	0.441	0.066
6. Dodge & Romig Single Sampling (10% LTPD)	100	5	33	1	0.509	0.464	0.045
7. Dodge & Romig Single Sampling (10% AOQL)	50	5	7	1	0.844	0.862	−0.018
8. Dodge & Romig Single Sampling (10% AOQL)	100	10	12	2	0.879	0.903	−0.024

* Probability of acceptance of a lot having D defectives.
** Normal and single sampling level one.

To demonstrate these differences in terms of their effect upon protection offered in a sampling plan, we must examine the operating characteristic curves based on these two probability distributions. Typical OC curves calculated from Poisson and hypergeometric distributions for the same sampling plans are plotted and shown in Figures 2 and 3 for the purpose of this comparison. One can observe that for low percent defective Poisson underestimates hypergeometric or true probability and for high percent defective the opposite is true.

In making a comparison of the OC curves shown in

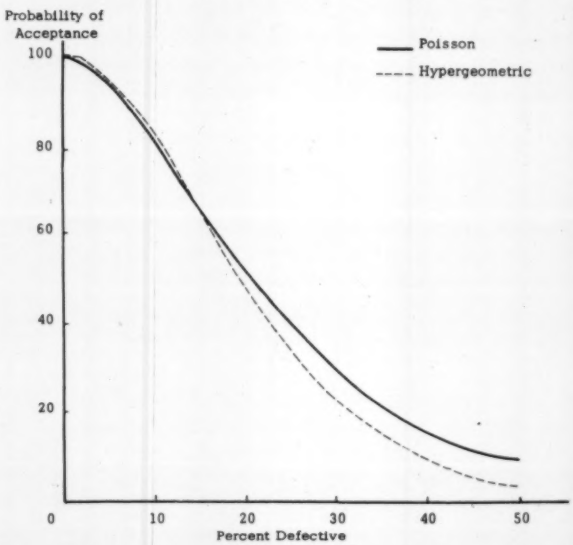

FIG. 2. Sample OC Curves Comparing Poisson and Hypergeometric $N = 50$, $n = 8$, $c = 1$.

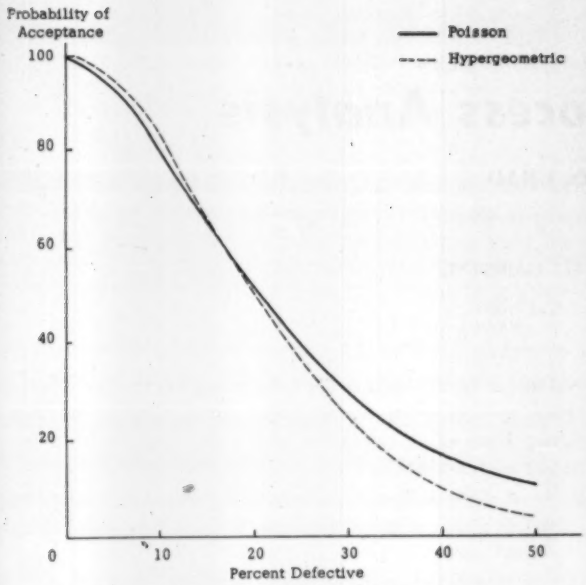

FIG. 3. Sample OC Curves Comparing Poisson and Hypergeometric $N = 100$, $n = 8$, $c = 1$.

Figure 2 with those shown in Figure 3 at a point defined as consumer risk in LTPD plans, we note that the Poisson underestimates protection offered to the consumer. In making a further comparison between Figures 2 and 3 at a point defined as producer risk by MIL-STD-105A plans we note the underestimation of protection offered to the producer.

To study the effects of the difference between Poisson and hypergeometric on the existing sampling plans, the probabilities of acceptance of lots by various sampling plans are calculated by both the Poisson and hypergeometric distributions. These are shown in Table 1. The direction of error $(P\text{-}H)$ term, again bears out the fact

TABLE 2

	$N = 70$				$D = 21$			
d	$n = 1$	$n = 2$	$n = 4$	$n = 8$	$n = 12$	$n = 16$	$n = 20$	$n = 24$
00	0.7000	0.4869	0.2311	0.0478	0.0087	0.0013	0.0002	0.0000
01	1.0000	0.9130	0.6530	0.2388	0.0662	0.0147	0.0026	0.0004
02		1.0000	0.9224	0.5499	0.2284	0.0719	0.0176	0.0033
03			0.9935	0.8186	0.4852	0.2127	0.0710	0.0181
04			1.0000	0.9529	0.7390	0.4354	0.1948	0.0664
05				0.9926	0.9033	0.6744	0.3928	0.1757
06				0.9994	0.9746	0.8542	0.6192	0.3544
07				1.0000	0.9954	0.9506	0.8078	0.5698
08				1.0000	0.9995	0.9876	0.9238	0.7640
09					1.0000	0.9978	0.9767	0.8960
10					1.0000	0.9998	0.9946	0.9639
11					1.0000	1.0000	0.9991	0.9903
12					1.0000	1.0000	0.9999	0.9980
13						1.0000	1.0000	0.9997
14						1.0000	1.0000	1.0000
15						1.0000	1.0000	1.0000
16						1.0000	1.0000	1.0000
17							1.0000	1.0000
18							1.0000	1.0000
19							1.0000	1.0000
20							1.0000	1.0000
21								1.0000

that the sampling plans based on the Poisson distribution underestimate protection offered at the two points known as producer and consumer risk defined by LTPD and MIL-STD-105A plans. The $(P\text{-}H)$ term for all these plans is significant and they range from -0.024 to $+0.066$. This indicates that the existing sampling plans for small lot sizes must be based on hypergeometric rather than on Poisson probability distribution, if practitioners are to be appraised of true risks involved when employing sampling plans on small lot sizes.

Table 2 is a set of tabular values of probability of acceptance (for acceptance numbers ranging from 0 to 21) based upon the hypergeometric distribution. This table is a sample of the type derived for values of N from 50 to 100 in increments of five. The tables derived to date tend to indicate the need for a complete set of tables, in order to provide the practitioner with adequate data to develop true sampling plans.

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Information Process Analysis

by **BURTON GRAD**

General Electric Company, New York

and **RICHARD G. CANNING**

Consultant, Vista, California

INFORMATION Process Analysis is a new charting technique developed by the General Electric Company to aid the introduction of electronic data processing systems in the office. Actually, it has applications considerably beyond this original purpose. However, the present discussion will deal primarily with its application to electronic data processing.

The introduction of electronic data processing equipment is forcing a greater awareness of the *systems* aspect of information processing than has, say the introduction of punched card techniques. Because of their speed, cost, and capabilities, these EDP systems are causing management to cut across existing functional lines in the development of new procedures. This is true not only of the different areas within the office but it is becoming equally true in the integration of office and factory.

How is this systems concept different from what has been done in the past? In a relatively few cases, procedural work has had a true systems approach. However, in the vast majority of cases, the emphasis has been on cost improvement projects designed to do a certain part of the business in a more efficient manner: for example, better methods for drilling a hole or for preparing factory paperwork: substituting a less expensive part which will perform the same function as the previous part, and so on. Most of these projects do not consider (or consider only briefly) the *inter-relationships* between the various activities of the business. The "bricks" are analyzed in great detail but the composition of the "mortar" is too often ignored.

There always seem to be numerous valid reasons for *not* studying these interrelationships. First, they are more difficult to analyze than are the activities themselves, and require a broader knowledge of the total business. The system interrelationships cut across existing functional and sub-functional lines so that no one is quite sure to whom they belong. Finally, their study takes longer and does not have the glory of an immediate reward.

Even in the face of these arguments, however, experience has shown that the "bits and pieces" approach by itself cannot produce the gains which can be realized from a study of the business as a whole—a systems study. Also, the advantages of electronic data processing lie, to a great extent, in tying together logically related activities. Maximum system speed and accuracy result from integration along lines of information flow, rather than within individual functions.

In a systems study, care must be taken to make the analysis much more comprehensive than the usual "procedures" analysis. Improving a particular process or activity is not the primary goal, but rather examining the necessity for having the process at all. This approach is not hardware-oriented; it is an effort to find out *why* things are done at all and then, after constructing a logical pattern for operating the process, to determine the real equipment needs.

The Information Process Analysis technique to be described was designed to meet the needs of such a systems study.

THE SYSTEMS APPROACH

In beginning an EDP systems study, we are more interested in *what* is going on in the business rather than in *how* it is being performed or *who* is performing it. For example, there are certain types of information which, though of interest in a conventional procedures study, are *not* of interest in a systems study:

1. We are not interested in the manual procedures that are used per se—e.g., how many clerks and typists work on a form during its preparation, or points along its route where the form is stored temporarily.
2. We are not interested in the fact that several people are involved in an operation, each doing part of the over-all job.
3. We are not interested in the layout of the clerical work area or the types of office equipment used.
4. We are not interested in the "exceptions" which arise due to internal clerical errors; however, we are interested in the types of information errors transmitted into the organization from outside over which the organization has no control.

Instead, since we are interested in learning *what* the mechanized system must be able to handle, we *are* interested in the following types of information:

1. The logically necessary alternative procedures which are needed in the business for handling main line flows as well as so-called "exception" cases.
2. The management control reports that are developed by the organization, and the purposes they serve.
3. The reports and other pieces of information that must be

transmitted outside of the organization, for legal or other reasons.

4. At first, a preliminary pin-pointing of all complex computation operations and decision areas. Later, we will need a more detailed understanding of these operations.

Conventional charting techniques usually involve symbols representing such clerical activities as transport, store, delay, inspect, and a general symbol representing all operations. These conventional techniques have been aimed at, and these symbols are useful for, one of two main objectives: a. to find out where human clerical time is being spent, so as to shorten the over all process time, or reduce the man-hours to do a job, or b. to lay out a prescribed sequence of operations for a reasonably complex job, for the guidance of the clerks and operators—e.g., flow charts of punched card operations. Since our primary interest in a systems study is not in either of these objectives, it is not surprising that their associated charting techniques prove relatively ineffective in a systems study.

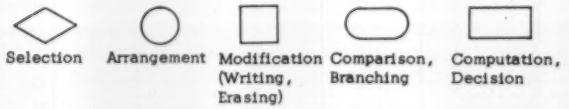
Instead, we are interested in learning of the flow of information throughout the business, for directing manufacturing and other activities, and for feedback and control. *All* uses of the information must be accounted for, so we soon find the scope of the systems study spreading throughout the entire organization. The Information Process Analysis technique designed to meet this objective is based on: a. reasonably precise definitions of basic data processing operations, represented in the form of symbols, and b. a charting procedure to make sure that the necessary descriptive information accompanies each symbol.

In other words, conventional charting techniques treat information systems as though they were material handling systems, where the material is paper. Since this new technique deals with the information itself, not the paper, we are able to concentrate on the different data processing operations.

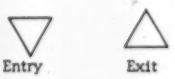
INFORMATION PROCESS CHARTING TECHNIQUE

Fundamentally, there are only seven symbols used, five of them representing operations (where someone does something), and two representing conjunctive, or connective devices. These basic symbols are shown below:

OPERATIONS



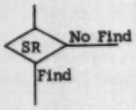
CONNECTIONS



In practice, there are variations for some of these symbols, so that a total of 11 different terms are used. Each of these 11 terms and symbols is described briefly.

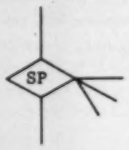
The Charting Symbols

1. Select, Search (SR)



Search means to extract a particular record from a file of similar records which are sequenced by the field on which the search is being conducted. Illustration: Search the Planning File for the Planning Card covering part number 374255-1.

2. Select, Separate (SP)



Separate means to select one or more records from a group or file, according to a key field. Sequencing by the key is not necessary. Illustration: Separate the copies of the Purchase Order by destination.

3. Arrange, Sequence (AS)

Sequence means to arrange (sort) a group of records into ascending or descending order according to a key field. Illustration: Sequence time cards by employee pay number.

4. Arrange, Merge (AM)

Merge means to combine two or more groups of records which are already in sequence by one or more key fields into a single sequence on the same keys, or to place a record in a file. Illustrations: Merge new Parts Lists with the Parts Lists File by Parts List number; merge the employee time cards with the employee job cards by employee pay number.

5. Modify, Insert (+)

Insert means to create a new record or to add one or more fields of information to an existing record. Illustrations: Prepare a new Purchase Order; sign a Freight Bill.

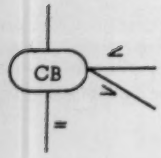
6. Modify, Delete (—)

Delete means to remove one or more fields of information from an existing record. Illustration: Delete a terminated employee's pay number from the active employee ledger.

7. Compute (CT)

Compute refers to an arithmetic formula incorporating basic arithmetic operations: Add, subtract, multiply, divide, exponentiation, trigonometric functions, etc. It does not contain any comparison or choice operations. If the result of a computation is used in a comparison, this should be indicated separately. Illustrations: Total week-

8. Compare and Branch (CB)



ly pay equals hourly rate times number of hours worked; stock on hand at end of period equals initial stock plus receipts minus disbursements.

Compare and Branch is the basic choice operation which involves a defined or fully prescribed decision. Illustrations: If the product model number is incomplete, then pass the order to Engineering; if an employee's accumulated salary year-to-date is greater than $4200, do not deduct social security.

9. Decision-Making (DC)

Decision-Making is a higher level than Compare and Branch. It is used when a choice is not based on a clear cut set of rules; in other words, judgment is involved in a decision-making process. It is possible in a decision-making operation to indicate what factors are considered and often even the relative importance of these factors. To the extent that exact "weights" can be determined and all alternate paths noted the operation reduces to a series of Compare and Branch operations. Illustrations: Determine the quantity of Model XYZ that will be sold within the next 12 month period; decide whether a job applicant is suitable for a particular task.

10. Connection, Entry (EN)

An *Entry* serves to start a routine or to bring additional information into it. It may come from another part of the same chart or from a different activity entirely. Illustrations: The customer order entering the order service routine; a pay voucher coming to Cost Accounting from Payroll.

11. Connection, Exit (EX)

An *Exit* is the means by which an activity is terminated. It may go to another part of the same chart, it may go to another activity, or it may be the end of the routine. Illustrations: All requisitions requiring special engineering review go to Engineering; a pay check is given to an employee for his previous week's work.

The foregoing descriptions are necessarily brief; more complete definitions for each operation symbol may be obtained from (1). A summary of their use on the charting form is shown in Figure 1.

EXAMPLES OF PROCESS CHARTS

To give an idea of the technique in action, we have included two examples, one trivial and one from an actual systems study. Figure 2 indicates some of the "data processing" operations which might be followed by a young man in search of a date.

The steps on the chart are relatively self-explanatory. Alphabetic entries and exits provide connections to and from other charts while numeric entries and exits refer to different parts of the same chart. Line 3 shows a routine decision step, involving a Compare and Branch operation, while Line 15 shows a difficult decision involving judgment. Line 8 shows the procedure for entering a new record into a file (merging). In general, it will be seen that the technique brings out clearly the various alternative circumstances that can arise. Also, space is provided for a brief explanation of each step in the process. Thus, charts drawn by one person may be easily read by others.

Figure 3 is a reproduction of one part of a chart on tooling activities in a manufacturing organization. The particular operation being charted is the receipt of raw material at the tool crib, where the material is destined to be made into a tool. Line 4 shows a searching for a copy of the purchase order after the material is received; the charter may or may not chart the "no find" situation depending upon how significant it is. Line 6 indicates that the tool crib attendant checks to see who the material is for; the "not equal" branch indicates that it is for someone else, and Exit 3 connects to the charting of that condition. Line 7 here refers to the fact that "someone else" to whom the material is to go wishes it to be stored temporarily in the tool crib; after it has been suitably marked in the other operation, the information again enters the main line being charted. The remaining operations

INFORMATION PROCESS CHART

Entries	Main Line Flow	Exits	Secondary Flow	Records		Record or Field		Fields	Remarks
	AM 1			Name of Record or File	By	Key	with	Name of File	
	AS 2			Name of Records Being Sequenced	By	Key			
	+ 3		on	Record onto which data is being inserted		Field(s) being inserted	from	Record from which data is obtained	
	− 4		from	Record from which data is deleted	Delete	Field(s) being deleted			
	CT 5			Field(s) being computed	from	Field(s) supplying information	on	Records from which field(s) were obtained	Formula, if easily obtained
	DC 6			Brief name of decision					List of major factors
	CB <, =, > 7		using	Record involved	compare	Field	with	Field	
				Record	and	Record	by	Field(s)	
	SR 8			Name of file being searched	by	Key	from	Record from which key was obtained	Do not search a record for a field
	SP 9			Name Records or file being Separated	by	Key			
		8			(Description of Exit 8)				
		9			(Description of Exit 9)				

FIG. 1

shown here indicate the steps taken to determine where to store the material in the tool crib. The original chart continues beyond line 10 for this one function, and in fact, eleven of these 18-line charts were used in charting the tooling activities.

EVALUATION AND SPECIAL PROBLEMS

The speed with which Information Process Charts can be prepared seems to bear a close relation to the speed of programming a problem for a large scale digital computer. Interviewing, charting, rechecking and summarizing result in about 2 steps per hour, although this improves with experience. Remember though that these steps are more powerful than the normal computer operation codes since each symbol may represent an entire subroutine like "Sequence," "Merge," etc.

As in any new technique there is a significant learning curve effect. As experience is developed, speed and accuracy improve considerably. It is also apparent that different types of problems require somewhat different viewpoints and charting "tricks."

In first applying the technique the procedure was described with brief examples to a group of trainees and first line supervisors and specialists. The initial charting accuracy was substantially less than expected, probably because the training techniques were at fault. It is our conclusion that the best teaching method would be a practical example (like receiving of purchased parts) performed individually by each member of the team and then discussed and analyzed as a group.

In choosing the particular format and charting arrangement much consideration was given to the location of the symbols. In contrast to the usual computer charting which uses a "large" sheet of paper and writes in each block a description of the operation, we felt that the in-line page type arrangement was more easily traced and understood by the non-charter, yet this produces its own problems in excessive numbers of sheets and a lack of "Gestalt" or total grasp.

Since grasp and insight are among the main reasons for choosing process charting in the first place, it would have been most unfortunate if they had been lost because of difficulties of paper representation. Two approaches were used to help solve this problem. First, the original process charting forms were modified to allow the parallel indication of a secondary flow beside the main line. This permits a visual continuity and apparently saves many exits and entries. The second solution was the introduction of summary charts which served to review the over-all pattern of a particular business activity. These gave a sort of index to the detail charts and helped significantly in grasping and absorbing the major implications of the activity.

It is also evident that this summary process is vital to the desired insight into the ramification of the whole business. In other words, there needs to be a hierarchy of summarization eventually leading to a "Master Diagram" of the key processes in the business.

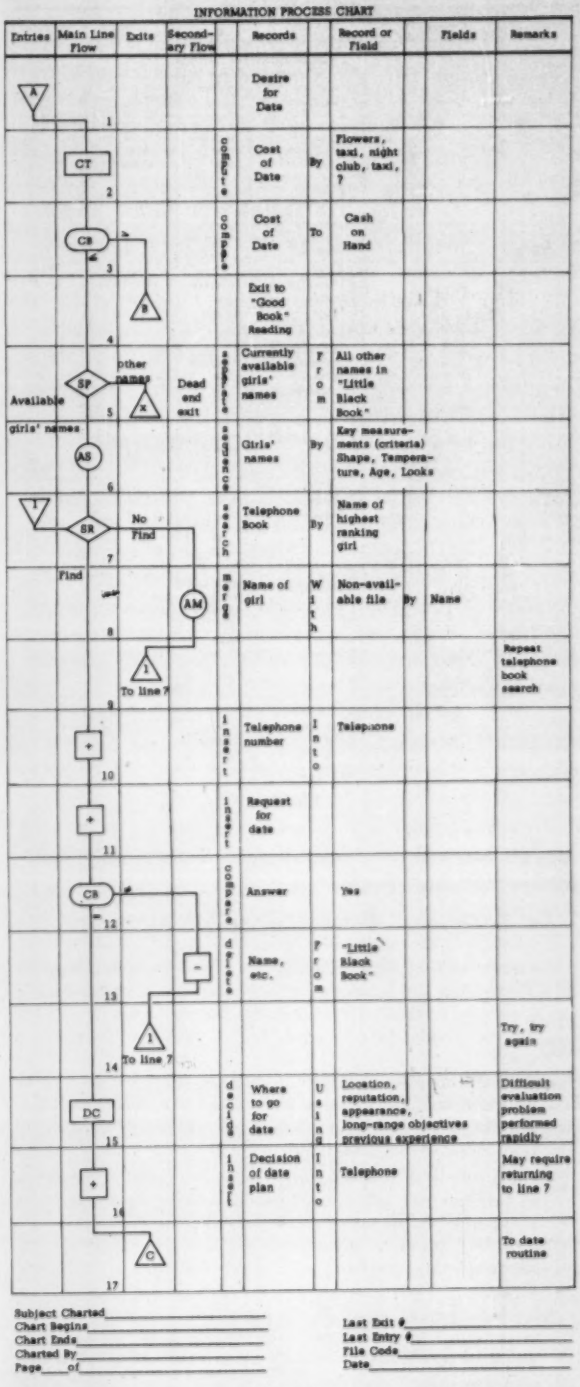


FIG. 2

To elaborate on the charting, reference is made to the column headings shown in Figures 1, 2 and 3. The mean-

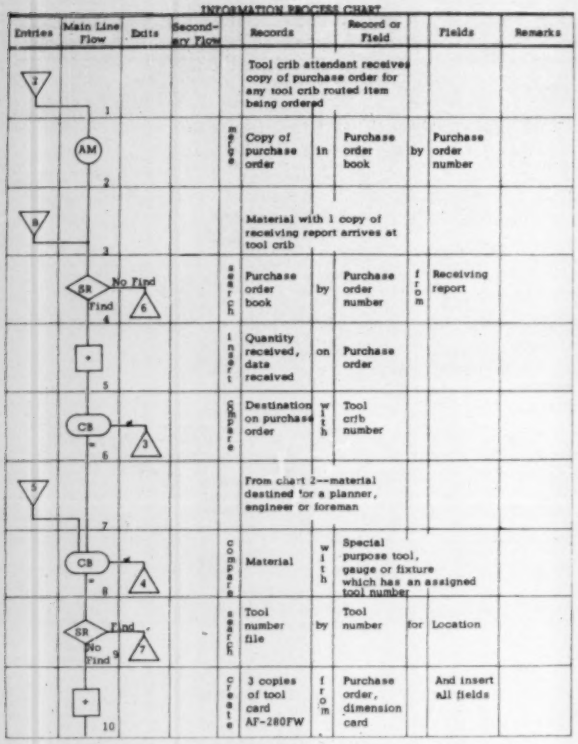


FIG. 3

ings are reasonably self explanatory. The following definitions of terms are quoted from (1):

File A collection of data, generally applying to one aspect of a business. A file consists of a group of "records" (to be defined), usually each of which contains the same type of information. The records are arranged (in most cases) in a specific logical sequence. Example: personnel file, inventory file, model list file, etc. (Note that the word "file" is used as a noun, not a verb.)

Record One member of a file; a record usually contains all pertinent information on a single item. Examples: a personnel record for one employee, an inventory record for a raw material type, or an entry in a log book.

Field A sub-division of a record; one or more related characters of data referring to a single aspect of an item. Examples: date of birth of an employee, employee's name, etc.

Character A character of data may be a numerical digit (0 to 9), an alphabetic character (a to z) or a special character ($, blank, @, etc.)

Data Known facts; generally, recorded facts, as used herein. The term "data" is often used synonymously with "information" although data generally include redundancy and errors as well as information.

Information Communicated knowledge (more precise engineering definitions are available but will not be presented here). It is important to know that information can be measured in terms of "binary digits" (bits), where each bit is equivalent to one yes-no decision.

Form A printed form used in manual data processing; generally is covered by the definition of "records."

Transactions A record of an event, an action. Examples: a new customer order, a shipment to a customer, an employee clocking in at work, etc.

Key One or more fields of data within a record used for controlling the handling of the record—sequencing, merging, searching, and separating. Example: Employee name in sequencing personnel records in the personnel file.

Main Line The predominant flow of data in the specific area being charted. A sequence of operations which is a secondary branch and exit on one page of a chart will generally be the main line on another page where it is charted.

All entries will be shown in the first column, properly numbered or lettered and page numbers for pertinent reference exits shown. The next column is where the bulk of the charting will be done—the main line, or the sequence of steps being described. The exit column is similar to the entry column.

The secondary flow column has been provided to reduce the need for exiting and re-entry to handle minor variations in procedure. We believe that the use of this secondary flow column should be quite restricted. For one thing, no separate entries should be made to the secondary flow column; rather, it is limited to branches out of the main line via Compare and Branch, Search, Separate, or Decision operations. In addition, if the secondary flow involves over 6 operation symbols, an exit should be made to another page of the chart, where it is charted as a main line.

There should be only one operation symbol per line—either an entry, main line, secondary flow, or exit symbol—so that the proper notation can be made in the other columns of the chart.

The three narrow columns which have no headings are provided for inserting prepositions, conjunctions or verbs. For example, "Insert *on* Record A Field X *from* Record B."

PROCESS CHARTING—DISCUSSION

There are a few points of special interest that should be discussed briefly, about the use of the foregoing symbols.

First, the operation of "reading" is implied in all of the above symbols, and is not called out as an independent step. It is assumed that the person or machine doing the processing must first read the information from the documents.

Next, it should be re-emphasized that whenever Compute and Decision-Making operations are encountered, the analyst should not initially spend much time in detailing the routines. The process charting simply pin points these computations and decisions, and gives some understanding of what is involved. After the initial data gathering phase, many of these operations will need to be analyzed in greater detail.

Occasionally an analyst will come across a "loop" operation, where the same series of steps must be performed on a number of items, before continuing with the processing. An example of a loop might be computing the

standard cost for each operation in making a part, before the standard cost of the finished part can be determined. Indicate such loops as simply as possible; e.g., "steps ——— through ——— repeated for each item on the record."

Also, in some possible loop operations (where there may be one or more items on the list), a totaling or summary is performed afterward if there were more than one item on the list. Do not try to chart this out, using conditional transfers. Simply indicate the totaling operation right after the last operation of the loop, and indicate in the Remarks column, that it is used if necessary.

Occasionally a matching operation will be encountered, such as a group of time cards being matched against a payroll file. It may be of interest to know if there are any time cards for which there are no payroll records, and if there are any payroll records for which there are no time cards, as well as matching the payroll records and time cards for computing gross pay. Such situations as this may be charted by two Search operations in sequence. In the case above, search the payroll file by the time cards' employee numbers indicating "Find" and "No Find." Then search the time card "file" by the payroll records' employee numbers indicating "Find" and "No Find."

The "and" and "or" concepts should be mentioned briefly. Sometimes two records must be brought together, so as to go through a series of processing steps; record A and record B. If record A has been charted as the main line, then record B can be brought in by connecting an "and" entry to the main line with a solid circle. See Figure 4.

Note that the "and" entry implies no merging, searching or sequencing. There is no file; only individual records are involved. Two or more records may be brought together, so as to form a larger record. If record A is being chartered as the main line and B is located in a file, then B should first be obtained by a Search operation.

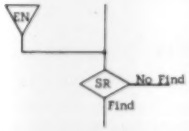


FIG. 4

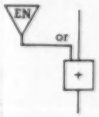


FIG. 5

For the "or" situation, record A *or* record B (but not both together) can go through the same sequence of steps. If the two types of records are similar or are logically related, it is often desirable to show this by an "or" entry and a second input line to an operation box, such as Figure 5. Then, at the end of the common sequence of steps, a Separate operation may be used to split the two types of documents apart. (A Compare and Branch operation is more correct logically, but the Separate operation is often easier to use.)

Sometimes, however, records A and B are so dissimilar that it would be confusing to use this "or" method. When charting the processing of record B, the analyst (when he comes to the same sequence of steps as he used in charting record A) can leave a blank line on his chart and insert the note, "Use steps ——— through ——— from page ———."

FUTURE USAGE POSSIBILITIES

We have tried to look ahead and deduce the logical implications of the process analysis technique and have found that many ideas can be suggested.

One idea is concerned with the use of punched cards for analysis of individual operations and the preparation of summaries. For example, by defining the records and fields carefully we could use one punched card for each line on the process chart. This is similar to work reported through the American Management Association by two Lehigh professors (4). This might be a convenient procedure for reducing the clerical content required to draw the flow charts.

Another possibility would be the evolution and development of higher level symbols to represent recurrent data processing elements. Examples of this might include edit, translate, and verify. These should be particularly meaningful for summary charting and would also indicate computer sub-routines which should prove useful.

While much of our present charting seems record oriented, this is merely a space reduction convenience. The record stands for or represents the fields it contains. Since all operations are performed on the fields themselves, it might be possible, with appropriate identification and coding techniques, to define all functions in terms of the fields instead of the records. This would be advantageous in leading toward nonredundant systems. Reference (3) is an extremely thought provoking paper on one aspect of this subject.

Since Information Process Analysis can be used to describe any data processing operation, it might be interesting to investigate the application of this language to computer programming. Because these charts are at a somewhat higher level than the charts now used, a significant saving in time and effort could result.

Another unexpected area which was uncovered was the strong similarity between physical processing and data processing systems. This is described in (2). As an analogy, we can consider that the part corresponds to record, and each hole, groove or surface is a field inserted in the record. Parts may be associated together in a "file" (stock room) which can be searched for a particular part. Compare and Branch can be used to represent inspection operations, and merge would imply parts accumulation to precede assembly. While this simile can be overdrawn, there nevertheless appears to be a sound foundation for further study with the implication that physical processing systems are directly analagous to data processing systems.

Since the process charting technique is organized around a generalized set of rigorously defined symbols, it may help to solve another common problem: the present inability to communicate solutions to various business systems problems. The Department of Defense has initiated a commendable program for the development of a Common Business Language—a computer programming system that uses English sentences which can be compiled into running programs for most machine types. But this Common Business Language will most likely be at a more detailed level than the language described in this paper, and may not be as satisfactory for communications at a systems level. It seems to us that the progress of data processing as a science requires establishing such common problem-oriented languages so that we can more successfully communicate with our fellow systems designers.

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(4) Richardson, Wallace J., and Heiland, Robert E., "Integrated Procedures Control," *Engineering for Paperwork Control*, American Management Association, Office Management Series No. 143.

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President's Message

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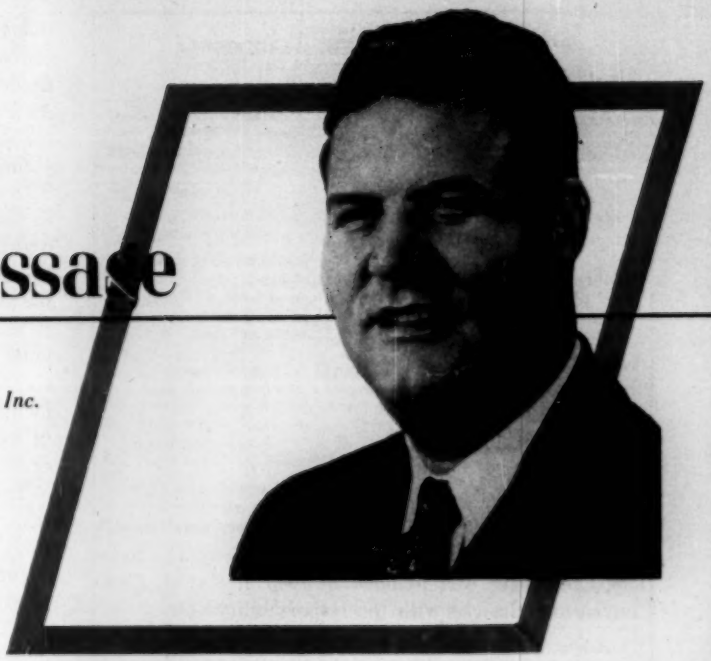

Professional Relations

ONE of the more important functions operating in behalf of our Institute is the Professional Relations Committee under the guidance of aggressive and dynamic Dr. Alex W. Rathe of New York University. Alex has served our organization in many capacities and has served both long and well. Currently serving on the Board of Trustees, he never fails to scrutinize every proposal coming before the Board to determine how the proposed action measures up to our responsibilities to our profession and to our relationship with other engineering societies.

Some idea of the complexity of this operation can be seen by a look at the basic organization chart of this committee, Figure 1.

The organization chart depicts the scope of the activity but not the depth. For example there are approximately 200 members working on some phase of this activity. This is indicative of the growth being experienced by our Institute in the scope of activities and technical development. Our growth is more than just an increase in the number of members.

A brief recap of current activities illustrates the tremendous amount of work that goes on behind the scenes:

Out of a total of 46 projects, 45 are active, with 171 different individuals participating as follows:

United Engineering Trustees: 2 projects

One of these is the United Engineering Center Member Gift Campaign. We have accumulated about $50,000 out of our $70,000 quota. It is anticipated that we will go over the top prior to the publication of this issue of the JOURNAL.

Engineers Joint Council: 21 projects

Engineers' Council for Professional Development: 3 projects

Engineering Management Conferences: 1 project

American Association for the Advancement of Science: 1 project

National Society of Professional Engineers: 1 project

Information Services: 3 projects

Task Forces: 14 projects, namely

- Standards in I.E. Education
- Criteria of Cooperation with Other Organizations
- I.E. Classification in U. S. Civil Service
- Professional Development Program at Chapter Level (program is in process of introduction to Chapters)
- Synchronizing other AIIE Activities with Professional Relations (currently inactive pending recommendations in AIIE Organization study)
- Unity in the Engineering Profession
- Professional Ethics
- Standards for P. E. Examination
- Membership Qualification Standards
- Qualifications for AIIE Representatives in Joint Activities
- Project Personnel
- Proposed AIIE Policy on Tenure of EJC Service
- Proposed AIIE Policy on EJC Activities
- Proposed AIIE Policy on Unionization of Engineers (submitted to Executive Committee in September)

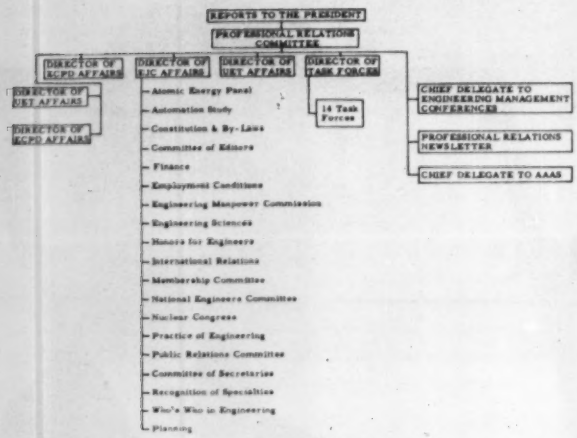

FIG. 1

We do not have to delve into history; we need merely to go back four years to find that the Professional Relations Committee was founded in 1955 at the St. Louis Convention, charged with the responsibility of:

1. Advising the President and National Board of Trustees of the AIIE on all problems concerned with cooperation with other societies, institutions and organizations in the field of engineering, science and management.
2. Participating in activities of joint interest on behalf of the AIIE.

This far-sighted decision established the means whereby we could more effectively take our rightful place alongside the other professional engineers in facing the problems common to the engineering profession. In retrospect we really had no choice except perhaps to deny or affirm the existence of our responsibilities as professional engineers.

At times it may seem to some that what we do at the national level of activity does not always appear to be of immediate value to the individual engineer. But just as surely as there is a relationship between the whole and the sum of its parts so is the final image and character of the Industrial Engineer related to and shaped by the sum total of all the single activities carried on anywhere within the organization.

The activities of the Professional Relations Committee probably affect more of us directly as individuals than any other group within the Institute. This is not too surprising when we review their assigned area of concern. The July-August 1959 issue of the JOURNAL carried a report in the "Institute Interests" section outlining the work done by this group which is well worth reading if you happen to have missed it.

For many years, accreditation of Industrial Engineering curricula has been carried on by the Engineers' Council for Professional Development. We now have a voice in this very important task, and competent Industrial Engineers have been selected to serve with the Accreditation Committee as members of inspection teams studying courses, plant, personnel, and other pertinent factors needed to assure competence in professional education. As a result we can now much more effectively help shape the academic training that we believe is necessary for the young Industrial Engineering graduate.

One of the biggest hurdles the new graduate faces is in closing the gap between the college campus and the realities of earning a living in society. The Training Committee of the ECPD has been studying this problem for over ten years and we have accepted their invitation to participate in this study. If you are a recent graduate your local chapter now has access to an outline of activities directed at furthering your professional development. Since this is a continuing problem, the experiences of local chapters with this program will be the subject of future study.

The single area of greatest coordination among the major branches of our profession has been through the Engineers' Joint Council in which we now hold constituent membership. The extremely high caliber of the work done by the EJC in carrying out its objectives has attracted nation-wide attention. We have participated directly in 26 EJC projects in the past year alone. Some of these—such as the Survey on Demand for Engineers and Salaries and Working Conditions—affect each of us directly; others—such as the Study of the Economical and Social Implications of Automation—have an extremely important bearing on the problems facing the nation in general and the engineering profession in particular.

Engineers have been directly responsible for the improvements in transportation and communication that have placed every country on earth only a matter of hours from each other. I need not review the significance of this fact other than to remind you that the problems of other nations, the learning and wisdom of other people, are bound to have more influence on our way of life than ever before. The Committee on International Relations of the EJC has done an excellent job of representing the American Engineer and Engineering in a very favorable manner to other engineers throughout the free world. These representations have been made possible primarily through meetings of UPADI (The Pan American Organization of Engineers of all principal nations in North and South America), The World Power Conference and the Conference on Large Dams (which were attended by representatives from over fifty countries). There is still so much that can be done to enhance still further good will among nations—in the field of education, for example, and the exchange of professional know-how, in order to raise the standard of living of mankind in general that we should continue to support this effort in every way possible.

Unity has long been expressed as a goal for the engineering profession. Perhaps like happiness, unity may be

a way of living rather than an objective. The close coordination, the feeling of mutual interdependence that comes from joint undertakings is certainly a form of unity in itself. Once a year, for example, leading engineers and managers come together to discuss problems of management engineering work. The participating societies have shared the financial responsibilities for this self-supporting event; and the AIIE—like the others—would have to assume a proportionate share of the loss if such an unlikely event were to occur. It has been the experience of the representatives involved that planning and arranging a major two-day conference of this type develop strong professional bonds between the participating societies.

Still another example of united effort is the new ten million dollar United Engineering Center now under construction in Manhattan. This center will stand as a majestic monument to the profession of engineering. Its occupancy in 1961 by the major engineering societies has been made possible by the individual efforts of thousands of engineers who have contributed time and money to make this dream a reality.

The Professional Relations Committee has undertaken and completed a number of specific assignments by establishing task forces made up of leading Industrial Engineers who have the qualifications best suited for the assignment. Some of these Task Forces, such as the one on Professional Standards, have studied problems directly concerned with developing material uniquely important to the current and future operations of the Institute. Others, such as the Task Force on Industrial Engineering Classifications in Civil Service, have provided a service to agencies or persons outside the Institute—in this case the Federal government.

A large number of people make up the Professional Relations Committee—all of them are busy men. Some hold down positions of great responsibilities in industry, in government agencies, or in the academic world. These men have two things in common: they are conscientious men who see a job to be done and come with their coats off and their sleeves rolled up; and, secondly, they are dedicated to a cause: to represent the professional interest of the Institute in such a way that the profession of Industrial Engineering will command the respect of their fellow engineers and of mankind in general.

These are activities in which we are needed—we have assigned some of the best minds in the Industrial Engineering Profession to these tasks—we should continue to do nothing less.

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ANNOUNCEMENT OF AIIE GRADUATE STUDENT PRIZE

General

The AIIE Graduate Student Prize for an outstanding paper on an Industrial Engineering subject is designed to stimulate and encourage scholarly interest in Industrial Engineering among graduate engineering students.

Eligibility

All graduate students regularly enrolled in an engineering curriculum are eligible.

Manuscript Submissions

Manuscript submissions will be accepted from any individual or group. In order to qualify for the Prize to be given at the National Conference in May, 1960, submissions must be received by the Committee before February 1, 1960. Submit nominations to:

Professor Norman N. Barish, Chairman
AIIE Research Awards Committee
Department of Industrial and Management Engineering
New York University
University Heights
New York 53, New York

Supporting Evidence

The manuscript, as well as supporting background material, source data, bibliography, etc., should be submitted to the Awards Committee. If more than one person contributed to the paper, the contribution of each participant should be explained in detail.

Criteria for Prize

In selecting the prize winning paper, the Committee will be guided by such factors as originality, depth, significance, universal applicability, and clarity of exposition. However, it is not expected that the paper will necessarily represent the results of original research on the part of the student.

Nature of Prize

The Prize will consist of a cash award of $250.00 plus a suitably framed certificate of award.

ANNOUNCEMENT OF AIIE RESEARCH AWARD

General

The AIIE Research Award is designed to stimulate and encourage research in Industrial Engineering by recognizing outstanding Industrial Engineering research accomplishment.

Nominations

Nominations will be accepted from any individual or group. In order to qualify for the Award to be made at the National Conference in May, 1960, nominations must be received by the Committee before February 1, 1960. Submit nominations to:

Professor Norman N. Barish, Chairman
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New York University
University Heights
New York 53, New York

Supporting Evidence

Complete evidence pertinent to the research as well as supporting background material, including biographical sketch, bibliography, etc., should be submitted to the Awards Committee. If more than one person contributed to the research, the contribution of each participant should be explained in detail.

Criteria for Award

In making its selection, the committee will choose from work recently completed, guided by the following criteria: originality, depth, significance, universal applicability, and clarity of exposition.

Nature of Award

The name of the winner will be inscribed on the AIIE Research Award Plaque which will be on permanent display at the National Headquarters of the American Institute of Industrial Engineers. In addition, the winner will also receive an award of $250.00 and an individual plaque.

Recent Readables

AUTOMATION

"Automatic Computation Speeds Pipeline Investment Analysis," T. R. Young, THE OIL AND GAS JOURNAL, *page 69, January 12, 1959.*

The application of automatic computation to economic analysis of crude-oil-pipeline investment has proved to be very practical. The computational work covers the basic design of a projected pipeline and estimation of construction and annual operating costs. These data are then used to develop financial information for evaluation of the proposed investment. Final output data are cash outlay and receipt schedules, payout period, and investment yield.

"Computer Control is Coming, But—," CHEMICAL AND ENGINEERING NEWS, *page 56, July 20, 1959.*

If ever a technique were on the verge of general acceptance, the application of computers to process control seems to be. One process—a catalytic polymerization—is already under such control, and others are following at a rapid rate. Before the end of 1959, you can expect to see at least three more chemical processes being computer controlled. And every large chemical company and petroleum company is studying the idea.

This report points out the promise and unsolved problem of this new area.

"How Computers Save Time, Trouble, Money," CHEMICAL WEEK, *page 119, May 9, 1959.*

Ever since computers moved into the field of engineering and scientific calculation, engineers have spent considerable time and ingenuity seeking new ways to solve increasingly complex problems by machine. Digital computers have taken over many of the engineer's time-consuming, routine calculating chores where accuracy is essential; analog computers provide a new way to keep tabs on the interrelated operations of complex systems in which many factors vary continuously. Here are three examples of how computers are saving trouble, time and money in engineering jobs.

"Scheduling and Control of Multiple Pipeline Tenders," W. G. Horstman, G. W. Chism, and W. R. McDonald, THE OIL AND GAS JOURNAL, *page 169, June 8, 1959.*

This article tells how and Why Plantation Pipe Line Company adopted an electronic data processing system as an aid in scheduling and controlling the movement of refined petroleum products through their pipeline system.

COST CONTROL

"Cost Control," by Phil Carroll, FACTORY, *March, 1959.*

Ignorance of product costs is still the weakest link in cost control, says the author, arguing that overhead costs are not being correctly analyzed and assigned to the products and processes that create them. In this discussion of the past, present, and future of cost control, he specifies three requirements for greater cost accuracy: 1. Prompter reporting of cost trends; 2. better interpretations of the facts and figures; and 3. cost facts that more correctly reflect profits or losses by products.

"Challenge Your Office Procedures with These Five Concepts," by John R. Crowley, AMERICAN BUSINESS, *March, 1959.*

Maintaining that many unexploited profit-improvement opportunities in the office methods field are going begging, the author focuses attention on five basic concepts involved in the analysis and evaluation of office procedures. He gives some concrete examples of how the use of these concepts can lead to greater efficiency and substantial cost savings in such areas as customer correspondence, invoices, salesmen's reports, purchasing requisitions, payroll operations, integrated data processing, shipping records, inventory control reports, and filing procedures.

"How a Pro Looks at Maintenance Cost Reduction," Carl Wyder, FACTORY, *page 222, June, 1959.*

Carl Wyder, *Factory's* editor of plant maintenance and engineering gave this hard-hitting talk at the 11th Annual Conference of the Philadelphia chapter of S.A.M. last February. What Carl said was so straight down the line of today's pressing needs that his associates insisted it be published. It will stimulate your thinking.

"Now They're Doing Something about Production Cost Accounting," by E. W. Ziegler, FACTORY, *March, 1959.*

Anarchy in cost accounting has resulted from rising fixed costs, a big change in the pattern of the labor force, and a general cost push, according to the author, who suggests that the remedy for this chaos may be the adoption of the direct costing technique. He describes how the direct costing technique works and cites the advantages it has over the standard absorption costing techniques now being used by most companies.

GENERAL

"Better Make-or-Buy Decisions," by E. B. Cochran, FACTORY, MANAGEMENT AND MAINTENANCE, *December, 1958.*

In addition to a worksheet for make-buy decisions and a table showing how a multiproduct line will affect such decisions, this article presents a breakdown of factors such as measuring costs, reviewing facts, weighing options, and figuring payoff timing, all of which are necessary for laying the groundwork in analyzing make-buy alternatives. It further cites four typical make-buy problems and points out how a reversal or modification of the ordinary solution can sometimes save money for a company.

"How You Can Hit the High Cost of Handling in Maintenance," John D. Wray, FACTORY, *page 94, June, 1959.*

No matter what your plant size is, you can weigh your chances of improvement in 10 minutes. Just answer the following 10 questions. They represent the cardinal sins in materials handling in maintenance. They are clues to how well or poorly you are doing in this field.

1. How often do maintenance workers stand idle at the job waiting for delivery of materials or tools?
2. How much time do your skilled maintenance workers spend in moving materials?
3. Do you need a large yard-labor gang for maintenance work?
4. Do your men have to carry heavy loads, say over 40 pounds, for any great distance?
5. Are men handling single pieces where unitized loads (palletized, banded, boxed) are easier?
6. Are men continually doling out material from large to small returnable containers?
7. How much equipment or material is damaged in maintenance for lack of proper handling equipment?
8. Do shops and storage areas allow easy in-and-out movement?

9. Are helpers on jobs used mostly to fetch and carry materials?

10. Does maintenance have its own materials-handling equipment, or does it have to beg, borrow, or steal from other shops?

To study materials handling in maintenance you should begin with four objectives:

1. To deliver material at the spot on time. If too early, it might be in the way. If too late, job cost is higher, downtime penalties are greater.

2. To deliver it to the right spot. If too far away, it may need rehandling. Various sources estimate it costs about $300 per man per year in some construction activities to procure materials 25 to 50 feet from the job.

3. To deliver it in the required amount for the job. Remember, it costs about $1 for that short trip to the storeroom for an extra length of conduit.

4. To deliver it packaged in a form most easily movable and usable, as well as most indestructible. For example, can you purchase concrete block on a pallet that can be rolled with a pallet truck directly to the mason?

"Human Engineering," Harold P. Van Cott, MECHANICAL ENGINEERING, *page 50, June, 1959.*

Human engineering got its start early in World War II. Before that time, psychologists in industry and government had been busy with problems of selecting and training men to fit machines. With the war, however, entirely new aircraft-control systems, radar gear, submarine sonars, gunnery systems, and other equipment were being developed. System reliabilities were often poor. Accident and injury rates were high. Careful manpower selection and training just weren't enough. Man-machine combinations weren't doing the jobs for which they were planned. The reason for this impasse was that machines were often making impossible demands of their human operators.

Human engineering is a young and unfamiliar field. It is sometimes misunderstood and misrepresented. But the rewards in improved machine operability, increased system reliability, and greater usefulness of man-machine systems to mankind have already been great. The unique contributions of human engineering are a combination of knowledge of human behavior and methods for the study of unknown areas of behavior with appreciation for the engineering problems of system development. More will undoubtedly be heard about it in the future.

"Integrating Your Transportation for Profit," DUN'S REVIEW AND MODERN INDUSTRY, *page 60, June, 1959.*

Fast-moving developments in transportation are bringing new profit opportunities for management. Key to the pay-off: integrating all the activities involved in getting goods to market. This Special Report to Management pinpoints what is now being done throughout industry to take advantage of new developments in physical distribution.

"Lease It—Don't Buy It," by Robert Sheridan, MANAGEMENT METHODS, *April, 1959.*

Equipment leasing frees working capital, permits major tax savings, provides a hedge against inflation, and offers a number of other advantages, says the author, who is president of a leasing firm. He explains some of the benefits a company can gain from leasing, and cites some case histories of companies that found it advantageous to lease needed equipment rather than purchase it.

"Five Steps to a Plan That Will Really Measure Your Managers," Carl Heyer, FACTORY, *page 62, February, 1959.*

If you're playing along with the trend to measure managers on performance alone . . . or if you're tearing your hair trying to shape a really useful management appraisal program . . . or if you've got a plan you think is pretty good . . . you could be wrong, all three ways. But here's a plan that wraps up the whole matter. It's factual, mature, comprehensive, carefully researched. It will show you it's time for you to take steps to a plan that will really measure your managers.

"Problem Solving Math Made Easy," Dorian Shainin, FACTORY, *page 84, June, 1959.*

Here are new "easy-does-it" approaches to statistical engineering.

Time and again experience proves that a small minority of causes will contribute a major share of total effect. For instance, when you break down standard output by operations, you usually find that a few out of many operations cause far more than half of the losses. Likewise, when you analyze all variations in an operation—that is, assign them to each of the sources of variation—you usually find that a very few sources cause most of the variation.

Thus the essence of the practical attack on avoidable costs is the pursuit of clues two ways:

The common-sense and "intuitive" approach of separating out probable important causes.

Then, with statistical aids, gradually refining the identification of all variables, one after the other, that have a significant bearing on results.

"The Reach of an Executive," by Stahrl Edmunds, HARVARD BUSINESS REVIEW, *January-February, 1959.*

The reach of an executive—his ability to reach down through the management layers to locate problem situations—can be extended if he has more complete, up-to-date data about current operations throughout the enterprise, maintains the author, who describes an effective reporting system, revolving around a 30 to 50-page management data report, now being used by the Ford Division of the Ford Motor Company. He tells how the system aided in the successful introduction of the four-door Thunderbird and in the early prediction of the 1958 recession, and suggests that the executive can effectively increase his span of control by organizing the information system around action-taking individuals who have demonstrated their ability to spot and report trouble areas.

INVENTORY CONTROL

"Using IDP for Inventory Control," by Frank H. Muns, THE CONTROLLER, *February, 1959.*

This case history describes how one company (Westinghouse Electric Corporation) set up an IDP system to handle the invoicing, shipping, and inventory control for 5,500 items in four warehouses receiving hundreds of orders daily from 20 sales offices in a five-state area. Through this system, the author reports, orders are fed into the central processing system, where the computer does the billing, feeds back information that enables the manufacturing divisions to adjust their production schedules, and transmits order information to the correct warehouse, where IDP automatically writes the shipping papers.

MATERIALS HANDLING

"Materials Handling in the Big 3," MATERIALS HANDLING ENGINEERING, *page 85, June, 1959.*

The material handling engineers who help make cars have been among the foremost in designing new handling techniques and equipment. They've had to keep ahead. The pressures of consumer demand have kept them hopping. And, helped by their research and manpower resources, they have led progress, not only in production handling but also in storage, warehousing, packaging, and shipping.

This progress is especially noteworthy for two reasons. First,

it happened with great speed. Second, it permeated the companies, including their top managements.

They aren't the only ones which have made big contributions to the science of handling in general. But, with the numerous innovations of the car firms, it's easy to see why so many other companies have already followed their patterns in material handling. More are sure to want to adopt their ideas after reading this feature.

"Work Sampling—Key to Reducing Cost of Material Handling Activities," R. T. Reul, W. J. Richardson, MODERN MATERIALS HANDLING, *page 88, April, 1959.*

This article describes the techniques of work sampling as applied to materials handling and gives examples of actual experience. Each example is organized to show the steps in taking the study.

OPERATIONS RESEARCH

"Dress Rehearsal for Decision Making—The Growing Use of Business Games," Joel M. Kibee, THE MANAGEMENT REVIEW, *page 4, February, 1959.*

How can an executive acquire experience in top-level decision-making without exposing himself and his company to the risks that inevitably go with it? One seemingly off-beat—yet highly practical—answer is the so-called "business game," in which years of business experience can be simulated and compressed within a single day of concentrated practice. Unlike other training techniques, business games provide feedback—enable participants to see the impact of their decisions in company P&L statements and other realistic measures of performance.

"Solving Your Plant Problems by Simulation," Paul Green and S. R. Calhoun, FACTORY, *page 80, February, 1959.*

At first glance, any relation between a roulette wheel and the hard-headed business of running a plant seems downright fanciful. But as many a plant executive knows, chance plays strange tricks. Machines break down unexpectedly. Workers don't show up. Shipments arrive late. And bottlenecks turn up in key operations. Sometimes these events seem to be a giant conspiracy to keep plant executives from doing the best job possible.

Chance events like these are a part of everyday life. Until recently, about all the most skillful plant manager could do was to prepare his defenses against them as best he could. Today, though, with easy-to-use, plant-tested simulation techniques, a plant executive can soften the impact of unlucky events—even make chance do useful work in solving some problems that defy statement in mathematical terms. It can be used to simulate future sequences of events, thus test various alternate plans on paper without disturbing the physical process.

QUALITY CONTROL

"Control Charts Without Calculations," Paul C. Clifford, INDUSTRIAL QUALITY CONTROL, *page 20, May, 1959.*

The usual control chart for variables requires a separate data sheet, a reasonable amount of arithmetic, and two charts. The computation of control limits frequently requires the elimination of some of the original data. And for shop personnel there is still confusion between control limits and specification limits. A method is presented in which individual measurements are plotted, thus eliminating the data sheet. Control limits are established by a process of measuring and counting. Such charts lend themselves to a variety of applications, some of which are considered. In particular this procedure gives a simple comparison of process capability and process achievement.

SUPERVISION

"Do Your Foremen Have Time To Direct Their Men," J. R. Kennedy, THE IRON AGE, *page 114, July 30, 1959.*

Surveys show that little more than half a foreman's time is spent in direct supervision of his department. The John A. Patton firm studied foreman workloads in three companies in which wage incentive plans were being revised.

Over a period of two man-weeks, 693 observations were made in three companies. These observations were made at predetermined times; but every foreman—without prior awareness—was observed at different times each day.

Breakdown in their duties and percent of time were: Materials Handling, 3.6; Production Scheduling, 23.2; Quality Control, 13.4; Labor Allocation, 8.4; Machine Allocation, 2.9; Machine Maintenance & Repair, 6.6; Housekeeping and Safety, .7; Employee Relations, 6.2; Union Matters, 2.7; Control of Count, 1.4; Standards, .7; Methods Application, 6.4; Personal Mail and Phone, 1.1; Out of Department, 22.7.

WORK MEASUREMENT

"Now Those Unmeasurable Jobs Are Measurable," Virgil Rotroff, FACTORY, *page 192, February, 1959.*

This is a review of the George Elliott Company's answer for measuring work which varies significantly from one item to the next. Multiple Factor Standards (MFS) have been used by the Elliott consultants for several years and they report no failures in their many applications. This article spells out the details of this technique.

BOOKS

"Proceedings from the Eleventh Annual Industrial Engineering Institute," Edited by E. C. Keachie, Copies Available from UCLA, 10851 LeConte Avenue, Los Angeles 24, California—$3.50.

The eleventh annual Institute covers a wide variety of subjects such as Streamlined Product Development; A Case Study in the Use of Operation Research Models Applied to Production Management Problems; Application of Computer Simulation to Sequential Decision Rules in Production Scheduling; Multi-Product Scheduling for a Single Production Facility; The Application of Planning, Scheduling, and Measurement to Maintenance Work; Multi Factor Wage Incentives—A Case Study; Labor Cost Contro. through Performance Sampling; and the Industrial Engineer's Crucial Role in Today's Business Climate, and others.

NOMOGRAPHY (2nd Edition), *by Alexander S. Levens, John Wiley and Sons, New York 1959, 295 pages, $8.50.*

MODERN ORGANIZATION THEORY, *by Mason Haire, John Wiley and Sons, Inc., New York, and Chapman and Hall, Limited, London, 1959, 324 pages, $7.75.*

MEASUREMENT: DEFINITIONS AND THEORIES, *by C. West Churchman and Philburn Ratoosh, John Wiley and Sons, Inc., New York, and Chapman and Hall, Limited, London, 1959, 274 pages, $7.95.*

SOME TECHNIQUES OF OPERATIONAL RESEARCH, *by Field Investigation Group, National Coal Board, London, 1959, 206 pages.*

HOW TO INCREASE YOUR CREATIVE OUTPUT—A GUIDE FOR THE ENGINEER AND SCIENTIST, *prepared by Deutsch and Shea, Inc., a publication of Industrial Relations News, 230 W. 41st Street, New York 36, New York, 1959, 22 pages, $1.50.*

SYSTEMS AND PROCEDURES RESPONSIBILITY, *by Philip H. Thurston, published by Division of Research, Harvard Business School, Boston, Massachusetts, 1959, 110 pages, $2.50.*

LABOR LOOKS AT AUTOMATION, *published by American Federation of Labor and Congress of Industrial Organizations, Washington, D.C., 1959, 28 pages.*

SYSTEMS AND PROCEDURES, *by Victor Lazzaro, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1959, 464 pages.*

HANDBOOK OF AUTOMATION COMPUTATION AND CONTROL, Volume 2, Computers and Data Processing, *by Grabbe, Ramo and Wooldridge, John Wiley and Sons, Inc., New York, 1959, $17.50.*

AN INTRODUCTION TO ELECTRONIC DATA PROCESSING, *by Roger Nett and Stanley A. Hetzler, The Free Press, Glencoe, Illinois, November 1959, 287 pages, $6.75.*

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Professional Relations

REPORT OF THE P-1 TASK FORCE ON PROFESSIONAL STANDARDS

At the Los Angeles convention in 1958 the National Board of Trustees commissioned a Task Force to investigate the desirability of formulating professional standards for Industrial Engineers. It was specified that this Task Force report directly to the Professional Relations Committee.

In July of 1958 the following persons were assigned to the P-1 Task Force on professional standards:

Dr. Lillian M. Gilbreth
Frank M. Gryna, Jr.
Harry L. Davis
Gerald Isley
Harold M. Scherr, Chairman

At its first meeting the members of the Task Force realized that the Board had committed them to an intriguing and challenging investigation: "That of determining the desirability of evolving professional standards for the Industrial Engineer: i.e., education, ethics, practical experience, professional competence, et cetera."

In broader terms, Professional Relations Committee Chairman, Dr. Alex Rathe, invited the members of the group to "take a broad look at the ramifications posed by the problem of professional standards in the practice of Industrial Engineering."

"The project specifically intends," he continued, "to be a top management view and *not* the detailed attack on the many items which comprise it."

Viewing the first quotation obliquely, it would seem that its authors might have had some prima facie doubt as to the desirability of formalizing a standards pledge for AIIE. That perhaps many AIIE members harbor reservations or see pitfalls in a declaration of professional standards for Industrial Engineers was considered during the several meetings of the Task Force.

Inasmuch as no work had been attempted on the specific subject of professional standards by any previous group or committee of AIIE, the group was not obliged to consider precedent from within AIIE. The Task Force attempted to do as much uninhibited thinking on the subject as possible.

The report as submitted is reproduced hereinafter:

The two questions following were examined by the Task Force and the conclusions summarized:

1. *Is There a Genuine Need for Professional Standards for Industrial Engineers?*

   Our group unanimously and emphatically feels that an urgent need exists for the establishment of professional standards, primarily to guide the practice of Industrial Engineering, and secondarily to delineate the field from other management arts and sciences.

   Although the American Institute of Industrial Engineers is the official organization of Industrial Engineers, it was noted that SAM had long since established a "rotating national committee" responsible for:

   (a) Developing minimum general and specific standards of qualifications for various classes of professional Industrial Engineering work.
   (b) Furnishing approved qualification data to engineering registration boards of various states for their consideration in establishing license requirements.
   (c) Developing a series of examinations to help in the classification of individual engineers into the above group.
   (d) Securing improved understanding in acceptance of professional standards on the part of Industrial Engineers, business executives, educators and the public.

   The misconception existing among the industrial public concerning the mission and purpose of Industrial Engineering is legion; this confusion exists not only in the middle and lower echelons of industry but is equally prevalent in top management.[1] It was the consensus of our group that, by and large, we are thought of as "technicians" and "fire fighters"—that while a formal declaration of professional standards will not endow our labors with professional status, it should significantly implement the over-all public relations efforts of the institute in this direction.

2. *What Areas Should Professional Standards for Industrial Engineering Encompass?*

   (a) *Professional Ethics*

   The Task Force agreed to recommend acceptance in the standards of the ECPD Canons of Ethics. It was noted however that without enforcement machinery, the Canons are of only inspirational value. It is further recommended that a tribunal with full disciplinary authority be commissioned to not only enforce the Canons, but to interpret them. (A supplementary function of this "watch-dog" group might well be to recommend appropriate additions to the Canons to cover specific violations or unprofessional acts in the practice of Industrial Engineering.)

   The Task Force members were able to recall at the New York meeting instances of unethical and undignified practices on the part of Industrial Engineers. Inestimable damage can be done to a young profession by a few unprincipled practitioners. It was noted that physicians have a unique system of regional "courts" wherein alleged violations of their code of ethical practice are adjudicated; and varying degrees of penalties assessed.

   (b) *Functions of the Industrial Engineer.*

   It was felt that if the *prime* functions of Industrial Engineering could be itemized in the Declaration of Standards, conceivably, some of the misconceptions beclouding the practice of Industrial Engineering could be corrected.

   One Task Force member observed that if every Industrial Engineer were to submit an essay entitled "What Industrial Engineering Means to Me," as many different shades of responses as there are Industrial Engineers would be gathered.

   Nonetheless, there are those specific functions and areas widely known and commonly agreed to be the sole province of the Industrial Engineer, and with little difficulty, these could be isolated. (If the National Board of Trustees looks with favor on the issuance of complete

[1] The president of a very large midwestern corporation recently questioned concerning his views on Industrial Engineering, still associated the Industrial Engineer with a caricature of an "efficiency expert" peering from behind the potted palms and covertly observing a machine operator at work.

professional standards, as herein recommended, the Task Force envisioned that perhaps they could be compiled in an attractive brochure and given the widest practicable distribution, as the information therein would be greatly enlightening to all levels of management.)

The Task Force did not want to be specific in recommending a list of functions for inclusion in the standards. To do so would be presumptuous in the light of the work already done by Dr. Andrew Schultz, Mr. Austin Weston, and other highly competent persons within the Institute.

Through the auspices of the Professional Relations Committee however, a questionnaire was attached to an issue of the "News Letter" and circulated to chapter presidents and members of the Professional Relations Committee.

The 86 responses received were tabulated and the functions checked by the respondents as a bona-fide I.E. function are ranked as follows:

Number Checking	*Function*
86	Methods Engineering
85	Performance Measures
84	Work Place, Plant, Office and Other Layout Design
83	Materials Handling
76	Operation and Management Research
76	System Design
75	Production Planning and Control
74	Inventory and Stores-Planning and Control
74	Standards Engineering
74	Job Evaluation
74	Economic Lot Sizes
73	Quality Planning, Analysis and Control
73	Economic Analysis
72	Mathematical Programming
70	Process, Tool and Equipment Planning
70	Statistical Analysis
69	Location and Site Planning
68	Standardization
67	Organization Planning
65	Forms and Procedure Design
65	Data Processing
59	Reports and Communications
54	Evaluation of Suggestions from Suggestion Systems
47	Safety Engineering
35	Personnel Analysis

"Write-ins" listed in the order of their frequency were:

1. Wage, Salary and Incentive Systems
2. Budgetary Controls
3. Work Measurement
4. Work Simplification
5. EDPM Feasibility Studies

This survey does not purport to have authoritative value; controls are lacking and the possibility of semantic deviation is great. The Task Force thought, however, that the results could be of possible interest to a committee investigating prime functions for ultimate inclusion in the Standards.

It was interesting to note the high percentage of response to the questionnaire and the receipt of some 40 personal letters and notes commending the possible project of developing professional standards.

Supplementing the foregoing concerning functions, it was felt that the following portion of a "minority report" recently received from one member is important enough to include herein for the consideration of the appropriate sub-committee on functions:

"In my opinion, Industrial Engineering is acting like an amoeba and becoming more and more fractionalized as time goes on. To others, particularly fellow engineering groups and other professions, we are presenting a picture of being 'jacks of all trades.' This I submit will not help us in our endeavor to gain professional status and professional recognition.

"I would suggest, therefore, that in this portion of the report we try to codify our role. Perhaps by making the point that we are primarily concerned with systems or operations engineering. Whether we are concerned with a single operation or an entire group of operations we should strive for the systems analysis and design approach. When we continually refer to such 'functions' as statistical analysis, work simplification, motion study, economic analysis, etc., we are merely talking techniques, and this I believe makes it almost impossible for people outside the profession to comprehend our true role. . . ."

(c) *Standards of Education*

The Task Force recommends that the Standard stipulate adherence to the accredited curricula leading to first degrees in engineering as subscribed to by ECPD; but that broadening of the basic educational requirements specifically for Industrial Engineers should be contemplated.

Here the burden of the Industrial Engineer as it differs peculiarly from that of his associates in the other engineering fields was considered.

An Industrial Engineer achieves his highest aims working by and through people. In his day to day and face to face relationships with individual human beings, he must be an artist as well as a scientist.

He is expected to do a thoroughly scientific job of originating a method, developing a technique or procedure—then, in many cases, he must artfully administer the change, over the twin obstacles of an antagonistic workforce and a pre-prejudiced management. Therefore, he should have a working knowledge of the "standard data" accumulated in the behavioral sciences since the Hawthorne Experiment.

In no other field of engineering endeavor is a strongly weighted curriculum in industrial psychology and industrial sociology so vital.

The Task Force recommends that the project of developing adequate educational standards for professional Industrial Engineers be placed in the competent hands of existing groups within the Institute.

(d) *Membership Qualifications*

It is recommended that the Standards contain the requisites for the various grades of membership as set forth in Article IV of the proposed constitutional amendment. It was most strongly felt by the group members that the membership qualifications should become ever more stringent and selective with each passing year. If ever increasing standards of membership are as well enforced as is the case at present, there will be little question in the minds of State Boards about the professional qualifications on licensing of an AIIE member.

Admittedly not germane to the task of developing standards, Task Force members had a lengthy discussion concerning the plausibility of originating examinations to qualify non-graduates for the various classes of membership with the additional thought that some State

Boards would welcome such examinations for use in professional registration. It was pointed out that several states continue to experience difficulty in determining the proficiency of Industrial Engineers, due to the limited or confused knowledge of Industrial Engineering functions on the part of State Board members.

Finally, the group recommends that the Standards begin with a lofty prefatory statement of purpose similar to that expressed in Section 1, New Article II of the Constitution and By Laws:

"To advance the general welfare of mankind through the resources and creative abilities of the Industrial Engineering Profession."

Respectfully submitted,[2]

HAROLD M. SCHERR, TASK FORCE CHAIRMAN

ADDENDUM

On the 15th of May at the National Convention, the Board of Trustees unanimously approved the Task Force report and its implementation by the five fold approach recommended by the Task Force.

Specifically, the Board was asked to:

1. Appoint a group to write appropriate supplements to the ECPD Canons of Ethics to restrict specific violations of ethical practice in Industrial Engineering, e.g. Discouragement of the undignified "hard sell" technique employed by some consultants might be a target of such supplementary provisions. Although Section 2 of the Canons touches on this, it is not considered sufficiently pertinent.
   (a) The same group should be charged with the responsibility of interpreting the Canons and determining when a violation exists in fact.
   (b) This group should also have an enforcement function and should recommend disciplinary action or expulsion from the institute to the Board for confirmed and documented violations.
2. To preserve the identity of the Industrial Engineering profession, a study group must be commissioned to inventory known I.E. functions for inclusion in the Standards.
   (a) With these functions clearly in mind a committee on Industrial Engineering education should draft standards of education for undergraduates, graduate instruction for I.E. bachelors, masters, and perhaps doctorates. These educational standards should be fully set forth in the main body of the Professional Standards.
3. Select a group to review membership qualifications and make revisions where necessary before stating them in final form through the Standards.
4. Appoint a group to determine the feasibility of examinations for admission into AIIE and for the possible use of State Boards for determining professional competence for state registration.
5. Form an Editorial Committee to make needed editorial revisions and to assemble the finished statement into an attractive brochure to be given the widest practicable distribution.

For the Task Force on Professional Standards

HAROLD M. SCHERR

PROFESSIONAL RELATIONS ACTIVITIES

The Public Relations Committee of the EJC is carrying on a quiet but intensive campaign to help clear some of the public confusion in regard to the role of the engineer in today's society. (The AIIE delegate to this committee is O. J. Feorene, Director of EJC Affairs.) One of the activities currently underway directly affects each of us and should therefore be of interest to all of you.

On November 19, 1958, a Public Relations Forum was held by this Committee in the New York Engineer's Club. The guest speakers at this forum were experts in Public Relations, editing, and writing for the public and included men such as Leo E. Brown, Public Relations Director of the American Medical Association and Earl Ubell, the Science Editor for the New York *Herald Tribune*. There were approximately seventy participants present representing editors of engineering publications, public relations men from the constituent societies and members of the EJC's Board. A complete report titled "What's Muffling the Voice of the Engineer" has been published by the EJC containing the presentations made by the eight guest speakers and a transcript of the discussion.

The Committee considered ways and means of improving communication with the general public. It was finally concluded that the surest and fastest way to get a message to journalists and broadcasters would be to buy advertising space in their business papers. A series of institutional type advertisements were planned, each attempting to sketch a simple statement of fact about engineers or engineering. The specific objective of this campaign was to overcome the lack of real understanding on the part of editors as to just what an engineer is and just what an engineer does. Scientists are continually being given headline attention while engineers appear to be playing the role of technician or technologist. The committee recommended that the funds acquired be used to purchase an initial series of six ads over the signature of the Engineers Joint Council in *Editor and Publisher* which is the most widely read trade publication in the journalistic field. Through this magazine, the messages should reach large newspaper, magazine, and industrial editors as well as television, radio and motion picture writers and producers.

The copy prepared by the committee attempts to clarify the status of the engineering profession and emphasizes the role that the engineer is playing in modern technological improvements. Quite frequently distortions appear in the press such as the rash of editorials involving the "shortages" or "layoffs" of engineers. These ads will direct the attention of writers to the fact that there is an organization—namely the EJC—that is in a position to be quoted as an authentic source of information concerned with engineers or engineering. These ads are also aimed in the direction of focusing attention on the *Who* as well as the *What* of engineering news events. All engineers will definitely benefit from a program of this type which is aimed at raising the professional dignity of engineers.

The Public Relations Committee of the EJC is convinced that this modest campaign will do much toward what Dr. Killian at MIT told the Electrical Engineers recently and that is "To extend the recognition that engineering is a creative activity that augments man's dignity and understanding and that affords him intellectual adventure of the highest order."

Enoch R. Needles, President of the EJC, has stated that "The engineers' hand touches every material thing used by the consumer to make his life a happier one. Our expanding economy is an engineered economy and it is high time people realized their obligation to recognize the men and women who are making it possible. We at Engineers Joint Council hope that our advertising program on behalf of all engineers will help to bring home to thoughtful persons the important place of the engineer in today's world. We further hope that reporters and editors will find the information in the ads helpful to them in putting the engineer in proper reference in the news stories of our advancing technology."

The first ad appeared in *Editor and Publisher* on June 20, 1959, and subsequent ads were scheduled to appear in intervals throughout the remainder of the year. Reprinted here are the first three of the public service advertisements in the series.

Reported for the Professional Relations Committee

BY HARRY L. DAVIS

[2] The Task Force wishes to acknowledge the constant cooperation and guidance of Dr. Alex Rathe.

One of a series

Let's get clear on— WHAT ENGINEERS DO

Simply stated, engineers apply the sciences to give people use of nature's materials, forces.

Scientists make it known. Engineers make it useful.

Scientists split the atom; engineers design and build the atomic power plants.

All science known would benefit nobody if not applied by engineers to manufacturing, construction, mining, agriculture or the generation of power.

These are the great engineered industries—all based on scientific knowledge.

Engineers plan, design, produce, maintain and *operate.* To repeat: *Scientists make it known. Engineers make it useful.*

Engineers Joint Council
29 West 39th St., N. Y. 18, N. Y.
For information call Pennsylvania 6-9220

One of a series

Say Engineer, When You Mean Engineer

Somehow it's become popular to speak of science and technology—popular, that is, with everyone but engineers.

Engineers are in a partnership with scientists in this great industrial nation of ours—designing its products, constructing its communications, and even producing its missiles.

The U. S. is reaping fruits of a highly developed technology—a vast body of engineering and scientific know-how. And the fellows with that know-how are scientists and engineers.

So when you speak of these fellows—or write of them—call them what they call themselves. Call them engineers.

Engineers Joint Council
29 West 39th St., N. Y. 18, N. Y.
For information, call Pennsylvania 6-9220

One of a series

Engineer Shortage? — Who Says?

From time to time statements are issued and news stories are published on either the shortage or over-supply of engineers. Some of these stories can be startling. Too often they are based on insufficient information.

The Engineering Manpower Commission—a committee of Engineers Joint Council, representing 20 national engineering societies and 300,000 of the nation's engineers—always has the up-to-date facts. For figures, such as the number of engineers needed, freshman enrollments, number of graduates, current salaries—phone, wire or write—

Engineers Joint Council
29 West 39th St., N. Y. 18, N. Y.
For information, call Pennsylvania 6-9220

CONTRIBUTED RESEARCH PAPERS FOR THE ELEVENTH ANNUAL NATIONAL CONFERENCE

A session at the Eleventh Annual National Conference of the American Institute of Industrial Engineers, in Dallas, Texas, at 2:00 P.M., on May 13, 1960, will be open for contributed papers by individuals doing research in the area.

Titles and abstracts of these papers must reach Andrew Schultz, Jr., Upson Hall, Cornell University, Ithaca, New York, by April 15, 1960. The title should include: title of paper, full name and initial of the author, his affiliation and address. The abstract should be carefully prepared to indicate the essence of the paper, the purpose, what was done, and the conclusion; and it should be limited to two hundred words, double spaced, with one carbon.

It is hoped that the membership will take advantage of this opportunity to report on research accomplishments.

CALENDAR

January 24-February 5: Executive Leadership Seminar, University of Arizona, Tucson, Arizona. This seminar will be limited to 25 top management representatives and is co-sponsored by the University of Arizona College of Business and Public Administration and the Cornell University School of Industrial and Labor Relations. Applications should be submitted prior to December 26 to: Dr. John W. Leonard, College of Business and Public Administration, The University of Arizona, Tucson.

February 1-11: Thirteenth annual short course in Quality Control by Statistical Methods will be offered by the Mechanical Engineering Department, University of Illinois, with the cooperation of the Division of Engineering Extension at Urbana. Write: Robert K. Newton, Supervisor, Engineering Extension, 116 D Illini Hall, Champaign, Illinois.

February 4, 5 and 6: Eighth Annual Material Handling Short Course, Price Gilbert Library, Georgia Institute of Technology, Atlanta, Georgia. This program will stress the engineering fundamentals of material handling. Attendance will be limited to 40. Applications should be submitted prior to January 29 to: Mr. Richard Wiegand, Director, Short Courses and Conferences, Georgia Institute of Technology, Engineering Extension Division, Atlanta 13, Georgia.

FINANCIAL STATEMENT OF AIIE

As required by Article VI Section 28 of the AIIE Constitution, the following financial statement is published as prepared by our auditors, Keller, Kirschner, Martin & Clinger, Certified Public Accountants.

Statement of Cash Receipts and Disbursements
for the year ended September 30, 1959

CASH RECEIPTS

Dues:		
Chapter		$ 30,959.29
Member		47,238.82
Associate		46,281.06
Affiliate		8,585.15
Student		3,838.50
Total dues		$136,902.82
Application fees		8,250.05
Journal subscriptions		10,530.92
Sale of books, kits, and supplies		1,403.80
Sale of Insignia		1,033.66
Use of mailing list		2,545.06
Conference proceeds		2,862.87
Interest		1,952.21
Unclassified		1,357.35
Total cash receipts		$166,838.74
Less bad checks returned		329.71
Net cash receipts		$166,509.03

CASH DISBURSEMENTS

Salaries and payroll taxes		$ 41,893.58
Rent		3,525.00
Communications:		
Postage	$ 6,012.90	
Telephone	794.00	6,806.90
Office supplies and stationery		4,286.65
Office equipment		1,175.50
Publications, printing, and engraving		5,146.97
Journal publication		37,140.00
Travel, hotels, and meals:		
Reimbursed expenses	$14,666.43	
Advances	5,000.00	19,666.43
Refunds:		
Rebates	$26,857.48	
Dues and fees	1,437.80	28,295.28
Insignia		649.10
Insurance and bank charges		257.30
Maintenance		454.91
Chapter expense		2,325.83
M.A.L.		130.50
E.J.C. membership		1,134.00
Mailing list rental		1,174.32
Ballots		1,095.93
Auditing		725.00
Conferences		656.77
Business administration		402.91
Contributions, advertising, and applications		313.25
Total cash disbursements		$157,256.13

UNEXPENDED RECEIPTS for the year	$ 9,252.90
CASH ON DEPOSIT at October 1, 1958	72,309.73
CASH ON DEPOSIT at September 30, 1959	$ 81,562.63

The cash on deposit at September 30, 1959, consists of the following:

Checking Accounts	
The Huntington National Bank—general account	$ 31,742.01
The Huntington National Bank—office account	354.36
Savings Accounts	
Buckeye Federal Savings & Loan Association	10,000.00
The Columbus Savings & Loan Association	3,000.00
Dollar Federal Savings & Loan Association	1,853.73
First Federal Savings & Loan Association	1,000.00
Franklin Federal Savings & Loan Association	9,453.37
Ohio Federal Savings & Loan Association	5,000.00
Park Federal Savings & Loan Association	10,000.00
The Peoples Savings Association	1,000.00
Scioto Savings Association	500.00
Standard Savings & Loan Company	6,659.16
State Savings	1,000.00
Total cash on deposit	$ 81,562.63

PERSONALITIES

PAUL CHAPMAN, JR.

On December 1, 1959 Mr. Paul Chapman, Jr., will assume the position of business administrator in the national headquarters office. He will succeed Mr. Don A. Trenwith who has held this position since 1955.

Mr. Chapman was born and reared in central Ohio and has had most of his work experience in this area. He was graduated from the Ohio State University with a degree of bachelor of science in business administration in 1951.

He has had varied experience in accounting, cost analysis, tax returns and in office and plant procedures and methods. He has had experience also in time study and methods analysis. He comes to us from the Mosaic Tile Company at Zanesville, Ohio, where he had charge of cost accounting and cost analysis functions.

We are glad to have Paul join us.

LILLIAN GILBRETH

Dr. Lillian Gilbreth, the woman renowned for the role she played in helping businessmen apply scientific management principles to industry, has been named to receive the 1959 International Systems Award.

It is commemorative plaque and a $1,000 honorarium sponsored by the Systems and Procedures Association.

According to David D. Merriman, president of the Systems and Procedures Association, Dr. Gilbreth was chosen to receive the Association's 1959 Award "in recognition of a lifetime of leadership and accomplishments in fields which contribute so fundamentally to the sciences on which systems work is based." The award was presented to Dr. Gilbreth at the banquet which concluded the 12th International Systems Meeting in Toronto on October 14. The meeting was scheduled for October 12, 13 and 14, and was held in the Royal York Hotel.

Dr. Gilbreth is the widow of Frank B. Gilbreth, originator of time and motion study. She has carried on in the field since his death in 1924. She has reared 12 children, two of whom—Frank B., Jr., and Ernestine—collaborated on the best selling book "Cheaper By The Dozen."

In addition, Dr. Gilbreth has been active in the fields of teaching, writing, psychology, research, education, civic and government affairs, lecturing and management consulting. She has written many books which include *Psychology of Management, Time Study, Fatigue Study, Applied Motion Study* and *Motion Study for the Handicapped.*

Significant awards and other recognition of her achievements have been expressed in recent years. They include the annual Woman's Association Award for Eminent Achievement, by the Society for the Advancement of Management and the Management Division of the American Society of Mechanical Engineers, the Gantt Medal award by the American Society of Mechanical Engineers, and the Wallace Clark award.

Dr. Gilbreth holds a Doctorate of Engineering from Rutgers University and a Doctorate of Science from Russell Sage College. She has received honorary degrees from more than seven leading Universities and Colleges.

RICHARD DAVIS HARRIS

Richard D. Harris, a student of Industrial Engineering at Virginia Polytechnic Institute, Blacksburg, Virginia, has been selected as the recipient of the first scholarship from the Dwight D. Gardner Scholarship Fund. The Dwight D. Gardner Scholarship Fund was set up by the American Institute of Industrial Engineers in honor of their first elected national president, and was established to aid in the furtherance of engineering education.

Mr. Harris' selection was announced in Columbus on August 13, by J. L. Southern, president of the scholarship fund.

The scholarship is for an amount of $750 and is for one year. Mr. Harris was chosen from a field of 31 applicants. He has been a student in the Industrial Engineering School at Virginia Polytechnic Institute since the spring of 1956. He formerly attended Case Institute of Technology in Cleveland, Ohio, and served in the Armed Forces for three years as a translator of the Chinese language. He is a member of Alpha Pi Mu and Tau Beta Pi Engineering Honorary Organizations. Mr. Harris makes his home at Overlook Acres, Stage Junction, Virginia.

H. B. MAYNARD

Dr. H. B. Maynard, President, H. B. Maynard and Co., Inc., management consultants, with headquarters in Pittsburgh, Pennsylvania, has been elected a Fellow of the International Academy of Management in Athens, Greece, it is announced by Professor Erwin H. Schell, chancellor of the academy. He is the fourth American to receive this honor, among the 26 nations of the Western World participating in the academy, according to Dr. Schell.

"Election as Fellow of the Academy," the citation reads, "is in recognition of distinguished services rendered to the science of management." Other Americans elected for membership include Dr. Lillian M. Gilbreth, originator with her late husband of the motion study technique and also "Cheaper By The Dozen" fame (popular best selling novel which tells her life story); Mr. Peter R. Drucker, well-known American economist and author; and Dr. Schell, who now heads the academy.

The academy was formed ten years ago as a means to research management information and knowledge and to disseminate it throughout the Western World. The academy acts as a subsidiary division of the International Committee for Scientific Management of Paris, France.

Dr. Maynard, according to the academy report, has made outstanding contributions in management to the fields of engineering, organizations, sales, and marketing. He is author of six industrial books, is editor of the McGraw-Hill Industrial Engineering Hand-

book, and was recently selected as author of their Top Management Handbook.

H. B. Maynard and Co., Inc., of which Dr. Maynard is president, has offices in Boston, New York, Philadelphia, Miami-Ft. Lauderdale, Chicago, and San Francisco. Their foreign branches are located in London, Gothenburg (Sweden), Madrid, and Buenos Aires.

WORLD-WIDE ENGINEERING AND SCIENTIFIC PUBLICATIONS

The critical needs of Engineers and Scientists for better access to the rapidly mounting volume of engineering and scientific publications are being studied by a Science Information Service under the leadership of the National Science Foundation. Dr. James R. Killian, Jr., Chairman of the President's Scientific Advisory Committee says "the increasing dimensions of world scientific publication has grown to the extent that it has become a problem requiring action at the national level. He said "science and engineering are largely built on the published record of earlier work done throughout the world. There are for example 55,000 journals appearing annually, containing about 1,200,000 articles of significance for some branch of research and engineering in the physical and life sciences. More than 60,000 different books are published annually in these fields, and approximately 100,000 research reports remain outside the normal channels of publication and cataloging. Within this vast body of world-wide scientific information, published and unpublished, lie the technical data that scientists and engineers need to do their work. The situation is further complicated by the fact that a large and important proportion of the world's scientific literature appears in languages unknown to the majority of American scientists and engineers—such as Russian and Japanese."

Nowadays Engineering Literature like missiles is directed on a world-wide basis. Furthermore the volume is such that, unlike conditions at the beginning of this Century, every engineer needs an international index service to keep abreast of the times. A good illustration proves the point. One of the Founder Engineering Societies in 1911 held an annual meeting with a total of fourteen papers—the same Society in 1958 at its Annual Meeting had 392 papers written by 656 authors, as some papers today are presented as a symposium, or prepared by two or more authors. Of the 392 papers only 165 will be published in full. Only 42% of the total papers presented before this important society meeting are made available to the engineering public. Only 298 were preprinted. Those preprinted are deposited in the Library of the Engineering Societies, and eventually are listed in the Society's Index of Papers; but this index is not available until eighteen months after some of the papers are presented, and then only those who consult that particular index may learn of their availability. Somewhat similar conditions exist regarding other national engineering societies.

The indexing of papers in the Library is handled by The Engineering Index, which is a non-profit organization. Since 1885 The Engineering Index has provided the most comprehensive indexing and abstracting service available to engineers and other specialists who must keep informed of technological developments all over the world.

Engineering Index employs a staff of qualified Editors who review over 1,500 periodicals and society transactions, as well as a large number of bulletins and reports of government bureaus, schools, institutes and research organizations. Publications in all branches of engineering and in all languages are reviewed. Articles which concern the application of engineering methods and concepts to any phase of the economy—and which are authoritative, informative, and useful—are abstracted.

The Abstracts are easy to use. For each article reviewed, the following information is printed on a 3×5 library card:

(a) Subject heading classification,
(b) Title of article and name of author,
(c) Name and date of publication,
(d) Brief summary of the article.

Subscribers to individual divisions receive all pertinent abstracts once a week. Subscribers to the complete service receive their abstracts daily—about 30,000 a year.

All publications reviewed are permanently filed in the Engineering Societies Library. The Library—which is open to the public—supplies, at minimum cost, photoprints, microfilm and translations of the complete text of any article abstracted by The Engineering Index.

Since The Engineering Index covers all of engineering, its service is divided into 249 "Field of Interest" Divisions. The subscriber who wants information in certain areas only, may take only the divisions he needs. The "Field of Interest" classification is for the convenience of subscribers in ordering particular divisions. For filing purposes, however, the literature is classified according to a standard list of subject headings. This makes it relatively simple to incorporate the abstracts into most reference files. The complete list of subject headings is supplied free to "Complete Service" subscribers and may be purchased by others—both subscribers and non-subscribers.

Subscribers use Engineering Index in the following way:

LIBRARIES—Engineering Index offers libraries—both public and private—a ready made index to much of the world's technological literature. In libraries with extensive collections of technical journals, the Index is a valuable key. Where there is no technical collection, or only a small one, the Index enables the library to serve many more users than it could otherwise. At the same time—by generating requests for publications—it may indicate to the librarian where to begin acquisitions.

INDUSTRIAL FIRMS—The major use of the Index is in industry where the pace of technological development demands a rapid, sure means of keeping informed. Here—in addition to its use in company libraries—are some of the functions Engineering Index performs for industrial subscribers.

General Employee Education—One large firm for instance subscribes to the complete service, reprints and distributes the cards to technical personnel, according to job interest. Other companies reprint the abstract information in their own abstract bulletins.

Research and Development—Here, where knowledge of technical developments can be critical, Engineering Index enables engineers to keep current without reading hundreds of publications.

Public Relations—Service organizations frequently subscribe to the Index to keep informed and to be able to answer consumer inquiries relating to their field.

TRADE ASSOCIATIONS—A subscription to one or several Engineering Index Divisions is an inexpensive way for a trade or industry organization to keep alert to developments which it can pass on to member companies. Some subscribers in this category also use the Index to keep a check on publicity received by members.

GOVERNMENT BUREAUS—Many federal, state and local government agencies are among Engineering Index subscribers. Included are military departments, experimental stations, departments of sanitation, highways, air pollution control, and water resources.

SCHOOLS AND UNIVERSITIES—Not only school libraries, but also individual departments and faculty members subscribe to the Index for their own purposes.

INDIVIDUALS—Many engineers and technological specialists subscribe to the Index personally simply to keep informed, or for reference and bibliographical help on specific projects.

The cost of The Engineering Index is economical and varies according to the volume of abstracts prepared from the special field in which the subscriber is interested. The literature abstracted

originates in 44 countries, and is published in 22 languages other than English. The space of time elapsing from the receipt of the publication until the abstract is distributed is reasonably brief and compares favorably with other services.

The Engineering Index Catalog will enable you to understand how simple it will be for you to obtain what you want from the mass of engineering information published in current technical engineering literature, no matter where it is printed. It is furnished in such brief and concise form that it will conserve your time, energy and expense, and keep you fully informed of what is worth while and pertinent to your interest.

The Engineering Index Service cards subsequently appear as a Bound Volume cumulating all of the references of the year. This volume, now in its 75th year, is an internationally accepted digest of technological literature prepared for engineers, research workers, and students. The Engineering Index has always been industry's authentic guide to the periodical technical literature. Today it still stands unrivaled. Engineers consider it a vital part of their reference equipment.

The progressive engineer knows that he must interest himself in all branches of technical research. He knows that the time has passed when he could limit his thinking to the field of engineering in which his immediate interests are involved. He realizes that he must be familiar with current developments in all phases of engineering and must inform himself concerning social and economic trends in order to assist in the solution of the major problems confronting humanity today.

INDUSTRIAL ENGINEERING RESEARCH AWARD

The American Institute of Industrial Engineers announces that the deadline for nominations for its annual research awards is January 1, 1960.

The awards consist of prizes for the best paper written on industrial engineering by a graduate student and for the best paper written by a person engaged in teaching, research, practicing industrial engineering or a related field.

For further information write:

Dean Norman N. Barish
College of Engineering
New York University
University Heights
New York 35, New York

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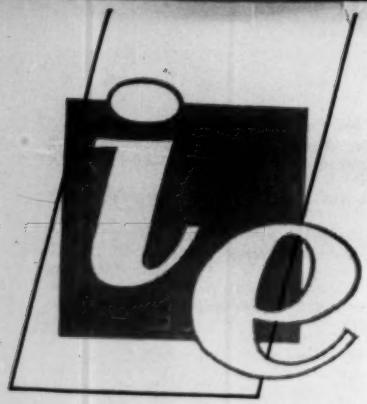

opportunities

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The I.E. Opportunities service is a functional committee activity of the AIIE. Information concerning employment opportunities is collected on a nationwide basis and is provided without charge to members upon request. The committee is composed of members from the Columbus, Ohio chapter.

SERVICES PROVIDED

Current job openings are published in condensed form in each issue.

In addition, a monthly I. E. Opportunities Bulletin is supplied to one hundred chapters located throughout the United States.

Each job opening is assigned a **"P"** number for identification. The name and address of the person to contact for additional information concerning a specific job opening is sent to members on request.

EMPLOYERS

Employers having openings for qualified Industrial Engineers are invited to list them. Government agencies and educational institutions as well as business and industry are urged to take advantage of this free service.

Industrial Engineers are often employed in such fields as Work Measurement, Production Control, Plant Engineering, Operations Research, Industrial Relations, Sales, and Management.

For a more complete coverage, see the following list of job classifications. Please do not hesitate to forward information on jobs in any area where it is recognized that an Industrial Engineering background will be of value.

To list your job openings with the Opportunities Service, send all or part of the following information with the name of your contact man to the address below: Type of industry, location, job classifications, minimum educational and experience qualifications, and salary range.

This information will be publicized to the members in condensed form in the JOURNAL and in monthly chapter Bulletins. Company names are not shown.

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The following list shows job openings available just prior to press time. If you would like more information about one or more of the positions listed, mail the **"P"** numbers with your name and address to the Opportunities Service at the address below. The Service will advise you by return mail of the name and address of the person to contact for further information, or advise you if the position is no longer available. Your name will not be forwarded to the company with the job opening.

For more current listings, contact your local Chapter Secretary or Opportunities Chairman for the latest monthly Bulletin.

ADDRESS OF THE SERVICE

I. E. OPPORTUNITIES SERVICE
American Institute of Industrial Engineers
145 North High Street
Columbus 15, Ohio

INDUSTRIAL ENGINEERING OPPORTUNITIES

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
41	Consulting	Ohio	×	10, 21, 31		5–7		
167	Weapons Systems	Wash. D.C.		50				Ph.D.
213	Air Force	Calif.		15, 3 , 42, 43, 44, 53	7.5–	2½–	21–	Repair & Modification
273	Air Force	Utah		11, 13, 18, 42, 43, 44, 53	6.3– 7.5	2–		I.E. Degree
279	Air Line	Ill., Colo., Calif.		11, 13, 18, 41–43, 50–52, 70	5.0– 8.5	1–6		
308	Automotive	Pa.		19, 36, 38, 53	6.6– 9.6	4–6		
339	Automotive	Pa.		11, 13, 15, 16, 22, 23, 36	6.6– 9.6	4–6		
340	Automotive	Pa.		13, 14, 15, 16, 22	5.4– 7.8	0–2		
352	Air Force	Ohio		50	5.7–12.5			M.S.I.E.
362	Aircraft	Conn.		50	Open	1–4		Milit. & Industrial Exp.
376	Education	Mass.					35–	
396	Administrative	Ohio		36, 37, 38	7.2– 7.8			
399	Pulp & Paper	Ala.		30, 40, 50		3–5	25–35	
414	Printing	Wis.		10	4.6– 6.0	0–3	21–	
419	Food Processing	Ill.		14, 15, 16, 22, 36, 38, 91	7.2– 9.0	5–8	30–38	I.E. or M.E. Degree
422	Air Force	Ohio		50	7.5–11.6			
423	Air Force	Ohio		Broad	8.8			
424	Air Force	Ohio		Broad	4.5– 7.5			
429	Aircraft	Calif.		10, 19, 32, 36, 38, 42, 43, 54, 71	6.6–10.5	2–10		B.S. or M.S. I.E.
436	Education	Puerto Rico		37, 53	5.4– 7.8			
444	Heavy Equip.	Ohio		10, 17, 21, 23, 72	Open	4–		Degree
447	Synthetic Fibers	W.Va.		10, 20, 30, 91	Open	3–5		I.E. Degree
449	Electronics	Mass.		30, 50, 70	6.0– 8.0	1–5		
459	Paper	Pa.		11, 37, 42				Pulp & Paper Ind. Exp.
461	Paper	Ohio	Ltd.	10, 20	9.0–13.0	3–5	–45	Tech. Deg. Req.
462	Navy	Alaska		48, 71	11.0–14.2	3–5		
463	Gen. Construction	Tex.		11, 13, 18, 33, 34, 36, 43	5.4– 6.6	1–	–30	—
464	Consulting	N.J.	×	10, 20, 32–34, 42, 43, 54, 71–73, 92	8.0–12.0	5–	30–36	I.E. Degree
465	Consulting	Mass.	×	10, 20, 30, 40, 70		5–	–35	I.E. Degree or Equiv.
468	Air Cond. Mfg.	Tex.		80	Open	2–	25–35	
469	Air Cond. Mfg.	Tex.		81	Open	2–	25–35	
470	Mining & Smelt.	N.M.		11, 13, 26, 36, 42, 45	5.0–7.0		–45	I.E. Degree Preferred
471	Plastic Prod.	Va.		10	10.0–12.0	5–	30–45	MTM Experience

Position number	Industry, location		Travel?	Job classification number (See key)	Salary range $1,000	Qualifications required		
						Years of exp.	Age range	Remarks
472	Plastic Prod.	Va.		11	8.0– 8.5	1–2	–30	MTM Experience (Woodworking)
473	Electronics	Iowa		19, 30, 40, 50	6.0–			B.S. or M.S. Degree
474	Food Processing	Ill.		14, 15, 16, 22, 36, 38, 91	5.8– 9.0	0–8	25–35	I.E. or M.E. Degree
475	Printing	N.Y.		11, 42, 44, 46		2–5	24–30	College Grad.
476	Metalworking	Ohio		13, 15, 36, 37	7.0–	2–5	25–30	
477	Metalworking	Ohio		53		2–5	25–30	
479	Brass Products	Conn.		10, 20, 36		1–5		Math. Experience
481	Non-Ferrous Metals	Conn.		11	8.0– 9.0	5–10	30–40	
483	Chemical	Tenn.		10, 30, 53	5.5–	1–5	22–30	I.E. Degree Preferred
484	Oil Seal	Ohio		11, 20, 31, 36, 42, 61, 93		5–		I.E. Degree
485	Electronics	N.Y.		10, 36, 42	– 9.5	5–		B.S.M.E./I.E.
486	Printing & Publishing	Calif.		18, 32, 36, 55	10.0–15.0		30–40	MBA Desirable
487	Electronics	Tex.		11, 16, 30, 32, 36	6.0–8.5	1–5	24–35	I.E. Degree
488	Gen. Construction	Tex.		50, 70	6.6–8.4	5–	–30	
489	Refining	Tex.			10.0–12.0	10–15		Exp. in Crude Oil Act.
490	Consulting	N.Y.		11, 35, 40, 53	8.0–12.0	5–	30–40	I.E. Degree
491	Airline	Ill., Colo., Calif.	15%	11, 13, 18, 51, 70	5.0– 8.0	1–5	–40	I.E. Degree Pref.
493	Plumbing Supplies	Ohio		11, 13, 18	7.5– 9.0	7–	30–35	I.E. Degree
494	Electronics	Utah		10–18, 34, 36, 40–46, 91	7.5– 9.0	5–10	30–40	I.E. Degree
495	Education	Fla.		Ass . Professor	Open	5–	30–	M.S. or Ph.D. Pref.
496	Air Force	Calif.		10, 11, 13, 15, 42–44, 72, 91	8.8–			I.E. Degree
497	Air Force	Calif.		10, 11, 13, 15, 42–44, 72, 91	7.5–			I.E. Degree
498	Air Force	Calif.		10, 11, 13, 15, 42-44, 72, 91	6.2–			I.E. Degree
499	Electronic Equip.	N.Y.		10, 36	Open	3–		I.E. Degree or Equiv.
503	Electronics	D.C.		30	9.1–11.7	5–		I.E. Degree
504	Synthetic Fibers	N.C.		10, 20, 32–36, 42, 43, 50, 53, 81		0–5		I.E. Degree
506	Railroad	Pa.		11, 13, 31, 36, 42, 43	5.7– 7.2	0–2	24–30	I.E. or I.M. Pref.
507	Railroad	Pa.		31–38, 51–53	7.2– 9.6	2–5	24–35	I.E. or I.M. Pref.
509	Electronic	N.Y.		10, 11, 13	7.0– 8.5	2–		I.E. Degree
510	Business Mach'y.	Mich.		40	6.5– 7.3		25–40	I.E. Deg. or Equiv. Exp.
511	Pharmaceutical	Mich.		General		0–5		I.E. Degree
513	Pulp & Paper	N.C.				2–5		MTM Exp.
514	Air Force	Ohio	25%	12, 17, 18	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
515	Air Force	Ohio	25%	40	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
516	Air Force	Ohio	25%	32, 37	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
517	Air Force	Ohio	25%	10, 13, 16	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
518	Air Force	Ohio	25%	Broad I.E.	8.8–10.0	4½–		B.S.I.E. or M.S.I.E.
519	Automotive Parts	Mich.		10		3–5		College Degree
520	Automotive Parts	Mich.		30		3–5		College Degree
521	Oil	Middle East		10, 20, 30, 40, 70, 90	15.0–20.0	10–	28–45	College Degree
522	Ind. Fastenings	Ill.		31, 43, 45	6.0– 7.5	1–3	–35	
523	Utilities	D.C.		10, 13, 18, 37, 50	5.7–	0–		I.E. Degree
524	Utilities	D.C.		10, 13, 18, 37	6.0– 7.0	2–3		I .E. Degree
526	Paper Prod.	Pa.		31, 35, 50–55	7.5–10.0	3–5	25–40	Adv. Degree
527	Consulting	Ind., Ill., Minn.	×	15, 22, 31, 41, 53, 91	9.0–12.0	10–	35–50	I.E. Degree Pref.
528	Farm Cooperative	N.Y.	×	Broad	8.0– 9.0	5–7		I.E. Deg. Plus B.A. Train.
529	Metalworking	Mo.		11, 34, 42, 43, 44	7.0– 7.5	2–4	24–40	B.S.I.E.
530	Paper Prod.	Mo.	×	15, 21, 36, 38, 42, 53, 54, 70	6.0–10.0	2–5	24–35	I.E. Degree
531	Consulting	Ohio	×	40, 50, 70, 80, 90	Open	5–15	25–40	B.S. Degree
532	Metal Fasteners	Pa.		11, 15, 19, 26	7.9– 9.0	5–10	28–40	
533	Chemical-Plastics	N.J.		31, 35	Open	4–	35–50	Prod./Inv. Control Exp.
534	Glass	N.Y.		11, 42, 43, 44, 45, 46, 47	7.0–	5–	30–40	I.E. or M.E. Degree
535	Automotive Parts	Mich.		11, 42, 43		2–		College Degree Pref.
536	Automotive Parts	Mich.		10		2–		
537	Printing-Litho.	Wis.		10, 20, 30, 70	8.0–	3–10		
538	Papermaking	Pa.		50, 51, 52, 53, 55	9.0–11.0	3–5	25–35	
539	U. S. Army	Ill.	×	37	10.1–11.0	4–		B.S. Degree
540	Instrument Mfg.	Iowa		11, 13, 43		5–7	–35	B.S.I.E.
541	Communications Mfg.	N.Y.		81	7.0– 9.0	3–	30–40	
542	Electronics	N.Y.		19, 42, 43	5.2– 8.5	0–3		B.S.—I.E., I.M., or M.E.
543	Air Force (Maint.)	Pa.		11, 13, 18, 44, 53, 91	7.5	4–	25–40	I.E. Degree
544	Consulting	Ill.		50–54	7.5–11.0	0–5	21–35	Adv. Degree Pref.
545	Consulting	Pa.	×	Broad	8.0–12.0	5–	28–45	
546	Consulting	Ill.		Broad	8.0–12.0	5–	28–40	
547	Home Appliances	Ohio		11, 13, 16, 21, 36	7.2– 9.6	4–6	25–35	I.E. Degree—Mtm. Exp.
548	Optical Supplies	Mass.		37	Open	2–3		
549	Air Force	Pa.		10, 11, 13–16, 18, 30–34, 39–47	6.2	2–	20–	I.E. Degree
550	Air Force	Pa.		10, 30–34, 39–47, 90, 91	7.5	3–	20–	I.E. Degree
551	Iron & Brass Fdry.	Canada			10.0–15.0	10–		I.E. Degree Pref.
552	Smelt. & Titanium	Canada			7.0– 8.5	5–10		
553	Sugar Refining —	Mass., Md., La.		11, 36, 38, 43	6.2–	0–5		I.E. Degree
554	Auto. Elect. Electro-Mechanical Equipment—	Midwest		10, 32, 42	15.0–20.0		38–46	E.E., M.E., or I.E. Degree

Key to Job Classifications

No.	Job Classification
10	Motion and Time Study
11	Methods Improvement
12	Suggestion Systems
13	Work Measurement and Perf. Stds.
14	Stop Watch Time Study
15	Std. Time Data Dev. & Applic.
16	Predeter. Elemental Time Stds.
18	Work Sampling
19	Estimating and Costing
20	Wage Payment
21	Incentive Plans
22	For Production Workers
23	For Non-Prod. Workers
24	For Supervisory Personnel
26	Job Evaluation
28	Wage Administration
30	Production Engineering
31	Production Control
32	Process Planning and Routing
33	Scheduling and Loading
34	Flow Process Charting
35	Inventory Control
36	Cost Anal. & Reduction
37	Statistical Quality Control
38	Budgetary Control, Standard Costs
39	Tool and Gage Design and Control
40	Plant Engineering
41	Plant Location & Expansion
42	Plant Layout
43	Material Handling
44	Machinery & Equipment
45	Specif., Select. & Eval.
46	Replacement
47	Automation
48	Plant Maintenance
49	Cap. Budget. Facil. Plan
50	Operations Research
51	System & Simulation with "Models"
52	Mathematical Analysis
53	Engr. Economy Studies
54	Auto. Data Proc. with Computers
55	Market Research & Forecasting
60	Industrial Relations
61	Personnel Administration
62	Personnel Testing
63	Personnel Training
64	Industrial Psychology
65	Labor Relations
66	Safety Engineering
67	Suggestion Systems
70	Systems and Procedures
71	Admin. & Operating Procedures
72	Organization Charts and Manuals
73	Records Admin. & Form Control
80	Product Design
81	Packaging
90	Management and Supervision
91	Industrial Engineering Supr.
92	Chief I. E. or Equiv.
93	Plant Engineer
94	Production Supervisor
95	Plant Mgr., Fact. Mgr., Works Mgr.
96	General Manager

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Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.